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The Role of Organisational Phenomena in Software Cost Estimation: A Case Study of Supporting and Hindering Factors

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Abstract

Despite the fact that many researchers and practitioners agree that organisational issues are equally important as technical issues from the software cost estimation (SCE) success point of view, most of the research focus has been put on the development of methods, whereas organisational factors have received surprisingly little academic scrutiny. This study aims to identify organisational factors that either support or hinder meaningful SCE, identifying their impact on estimation success. Top management's role is specifically addressed. The study takes a qualitative and explorative case study based approach. In total, 18 semi-structured interviews aided the study of three projects in three organisations. Hence, the transferability of the results is limited. The results suggest that the role of the top management is important in creating prerequisites for meaningful estimation, but their day-to-day participation is not required for successful estimation. Top management may also induce undesired distortion in estimation. Estimation maturity and estimation success seem to have an interrelationship with software process maturity, but there seem to be no significant individual organisational factors, which alone would make estimation successful. Our results validate several distortions and biases reported in the previous studies, and show the SCE research focus has remained on methodologies and technical issues.

Keywords: software cost estimation, project management, project success, top management, organisational factors, software improvement, software process maturity, case study

1. Introduction

Most software projects still suffer from budget and schedule overruns [1–4]. Regardless of the high price of software projects that bring hundreds of billions of euros in losses annually [5–7], there are still severe deficiencies in the proper application of software cost estimation methodologies in organisations [8–13].

Systematic overruns have continued for decades, although researchers and practitioners have developed hundreds of estimation methodologies [13, 14]. However, the reason for the overruns may not reside only in the estimation methodologies as they are shown to be able to produce accurate results when used properly [15, 16]. Thus, the problems that result in estimation errors may occur because estimation methodologies are used ineffectively by organisations [9, 11, 14]. Consequently, organisational inhibitors [10], top management focus [17] and the sources of distor-

tions [9, 12] have become the focus of recent studies.

While most SCE does not use a proper methodology, the situation is considerably better in the area of project management (PM) as, according to Fortune and White [18], only 5% of projects do not use any PM tools. Considering the fact that cost estimation is an inseparable part of all projects [19], and that the cause of overruns in software projects may reside in software cost estimation (SCE), project management (PM) or other areas [20–22], the difference in the extent of the use of methodologies between software project management and management of other types of projects is surprising. Especially, because commonly used industrial project management and process improvement frameworks, such as CMMI [23], PMBOK [19] and IPMA ICB [24], promote the importance of estimation and the use of methodologies. The use of proper methodologies is proven to have a positive effect on the outcome of both SCE and PM [18, 25, 26], nevertheless only PM professionals utilise these valuable tools and methods to any great extent.

As scientific literature or industrial advice does not provide a clear explanation for the gap in the extent of the use of methodologies between SCE and PM, one assumption is that the difference arises from organisational priorities and does not seem to be related to the availability of proven cost estimation methodologies. Project management is widely linked to the execution of the corporate strategy [27–29], but SCE seems to have very little visibility among top management. Also, while project management research paid close attention to non-technical factors, such as top management support, communication, skills and learning [18, 30], SCE research mostly focused on developing and improving estimation techniques [14]. This is an important observation, indicating that the explanation for the difference in the extent of use of SCE and PM methodologies could reside within the research areas omitted from the study of SCE.

The goal of this study is to identify organisational factors that either support or hinder meaningful SCE, and to establish their impact on estimation success. The study takes a holistic view with special attention on top management participation. A qualitative, exploratory case study approach is employed, using interviews as the primary data collection method. In total, three projects were studied and 18 semi-structured interviews were conducted.

Some research papers addressing SCE from the organisational rather than technical viewpoint have been published recently [9, 10, 17, 31]. This paper continues on this highly relevant path but diverges from previous studies by studying the impact of organisational factors related to software process or project process on the effectiveness of the use of estimation methodologies. Improving the understanding of the real-world dynamics related to the effective use of estimation methodologies may provide practitioners with valuable tools for improving SCE in organisations. Especially, the gap between the advice provided by the industrial project management frameworks and the low extent of use of methodologies could be narrowed. This study may also provide further evidence that organisational issues are equally important as technical ones for effective SCE, and generate new theories about the reasons for why the extent of use of methodologies is low regardless of the experienced importance of SCE and industrial advise. This would justify further study on the organisational dimension of SCE.

The remaining part of the paper is structured as follows: Section 2 presents related work focusing on four areas: software cost estimation, project management, top management involvement and software cost estimation in industrial frameworks. Section 3 presents the research questions. Section 4 introduces the case companies and projects, and Section 5 elaborates on the research design. Section 6 presents the results of the case study and is followed by a discussion of the key findings in Section 7. Section 8 concludes the study.

2. Related work

In the following subsections, top management's relationship to SCE and PM is reviewed and the

focus areas of earlier research on these subjects is summarised.

2.1. Software cost estimation

Software cost estimation is an activity that aims to produce a prediction of the effort required to build a software component. As most costs in software development projects are personnel costs, 'cost' and 'effort' are often used interchangeably. The literature that studies and develops methods to estimate costs in software projects began in the 1960s [32, 33]. However, despite five decades of research and hundreds of studies [14,34], software projects still exceed their budgets and timetables.

Jørgensen and Shepperd [14] conducted the most recent systematic literature review of SCE. In total, they selected 304 journal articles for their study and identified eight active research topics in SCE:

Estimation methods: the key issues include formal estimation models, expert estimation processes, decomposition based estimation processes and combinations of those three.

Production function: the key issues are the linear versus nonlinear relationship between effort and size, and the relationship between effort and schedule compression.

Calibration of models: the key issue is the calibration of estimation models, e.g. studies on local versus multi-organisational data and the calibration of the COCOMO model for certain types of projects.

Size measures: the key issues include validity and improvements in the size measures that are important in estimation models, e.g. the inter-rater validity of function point counting.

Organisational issues: the key issues are estimation processes in a wide organisational context, e.g. estimation practice, the reasons for cost overruns, the impact of estimates on project work, and estimation in the general context of project management.

Effort uncertainty assessment: the key issue is the uncertainty of effort or size estimates, e.g. methods providing minimum-maximum intervals for effort.

Measures of estimation performance: the key issues include the evaluation and selection of estimation methods, e.g. how to measure estimation accuracy or how to compare estimation methods.

Data set properties: the key issue is how to analyse data sets for the purpose of estimation methods, e.g. data sets with missing data.

Other: unclassified topics.

The distribution of the topics is presented in Table 1.

As shown in Table 1, all other categories except 'Organisational issues' and 'Other' focus on estimation methodologies or other formal methods for improving the estimation of size, effort or schedule. Only 16% of the articles discussed issues other than non-technical issues, i.e. organisational issues. Thus, SCE research strongly focuses on formal and technical issues and has relatively little focus on non-technical topics. Furthermore, the share of the articles focusing on organisational issues seems to be decreasing, it was only 14% during the period from 2000 to 2004. The recent study of SCE research trends shows also that the research focus has remained consistently on estimation methodologies and techniques between 1996 and 2016, the emerged research areas being 'size metrics', 'estimation by analogy', 'tools for estimation', 'soft computing techniques' and 'expert judgement' in five topic solution [35].

Estimation methodologies produce good results when applied properly [15, 16]. Regardless of this, overruns still continue. While an obvious research topic should be the effective application of estimation methodologies, 84% of the articles still focus on improving methodologies. Hihn and Habib-agahi noticed already in 1991 that only 17% of the estimators used proper estimation methodologies [36]. This, however, seems not to have affected the research focus either. Also according to our experiences, the basic problem of SCE is that the estimation methodologies are not applied properly; researchers and practitioners largely agree on this point [13, 14]. Furthermore, Jørgensen and Shepperd's [14] review reports that only eight articles out of 304 were in-depth case studies and only three evaluated the background to the estimation processes. This, together with the technical focus of the research,

Table 1. Distribution of research topics in software cost estimation. A single study can belong to multiple categories. Adapted from [14]

Perspective	–1989	1990–1999	2000–2004	Total
Estimation method	73 %	59 %	58 %	61 %
Size measures	12 %	24 %	16 %	20 %
Organisational issues	22 %	15 %	14 %	16 %
Uncertainty assessment	5 %	6 %	13 %	8 %
Calibration of models	7 %	8 %	4 %	7 %
Production function	20 %	4 %	3 %	6 %
Measures of estimation performance	5 %	5 %	6 %	5 %
Data set properties	0 %	1 %	2 %	1 %
Other	0 %	2 %	1 %	1 %

confirms that concentrating on real-world issues that prevent the effective use of SCE methods is justified as a systematic improvement in SCE success that can only be realised through the successful application of estimation methods in real-world situations.

2.2. Project management

The share of work organised as projects is very high in organisations, and the results of such projects are critical for the success of an organisation [37,38]. Due to the significance of PM, the topic has been broadly studied and the body of knowledge on it is extensive. Several different categorisations of PM research areas exist and the following six perspectives have been presented by Kolltveit, Karlsen and Grønhaug [30]:

The task perspective: key issues include the scope of project management for a task, project targets, project results and planning and control.

The leadership perspective: key issues are leadership, communication, uncertainty and learning

The system perspective: key issues are systems, elements of systems, boundaries and dynamics.

The stakeholder perspective: key issues include stakeholders, communication, negotiation, relationships, influence and dependence.

The transaction cost perspective: key issues are transactions, transaction costs, production costs, and governance structure.

The business by project perspective: key issues include business, project results, project success, strategy, profit and benefits.

In their article, Kolltveit et al. [30] identified 562 articles published in *International Journal of Project Management* and classified them into the six above mentioned categories (see Table 2).

Once again, when dividing the areas or aspects into technical and non-technical, the task and transaction cost perspectives can be seen as technical. The other four can be seen as non-technical, or at least having most of their key issues beyond the purely technical focus. As Table 2 shows, the focus of the project management research was shifting from the task perspective towards the leadership and business perspectives. This can be seen from the table as with the above classification into technical and non-technical aspects, the share of technical perspectives decreased from 68% to 18% between the first and the last period, respectively. This shift of focus seems reasonable since organisational issues are reported to be even more important factors in project success than technical ones [25, 39–41]. Top management support (TMS) was even suggested as the most important factor affecting project success [42], which corresponds well with the largest share of the leadership perspective related papers.

In comparison to SCE research, PM research underwent a major shift from task oriented or technical topics towards people oriented or non-technical ones, whereas the SCE research focus remains on task oriented subjects. Thus, it

Table 2. The distribution of research perspectives in project management. A single study can belong to multiple categories. Adapted from [30]

Perspective	1983–1987	1988–1992	1993–1997	1998–2002	2003–2004	Total
Task	49%	34%	32%	23%	12%	29%
Leadership	8%	16%	25%	28%	33%	23%
System	23%	25%	18%	19%	15%	20%
Stakeholder	1%	3%	1%	5%	6%	3%
Transaction	19%	9%	6%	10%	6%	10%
Business	0%	13%	17%	15%	29%	15%

is also reasonable to assume that the focus of PM research has placed more focus on how methods are applied by people and therefore increased the awareness, effectiveness and extent of use of the methods. The mere existence of a method seldom leads to its success.

2.3. Top management focus

Top management support has been found to be one of the most important critical success factors for project success in several studies [40, 42, 43] and few would doubt the need for TMS [44]. Also, top management's interest in PM is increasing along with the number of PM related articles published in top management and business journals [45]. However, top managers are generally more interested in non-technical issues of a strategic nature [46, 47].

The practices through which TMS is demonstrated for a project have been extensively studied. Garrity [48] recommends top management review plans and monitor results. Beath [49] found that top managers are able to make organisational changes, while Morton [50] notes top managers – as project champions – have the skills to mobilise public opinion, resolve conflicts between stakeholders and win the hearts and minds of project teams. Zwikael [25] identified a list of 10 critical top management support processes that influence a project's success, including appropriate PM assignment, project manager involvement during the initiation stage and the use of standard PM software.

TMS was not studied widely in the scope of SCE. However, Rahikkala et al. [17] found that top management pays attention to SCE and recognises that good estimates are critical for an organisation's success, as well as for understanding the consequences of an erroneous estimate. In general, there is very little information about TMS in SCE. This suggests that the actual top management focus on SCE is low. Regardless of the reported attention, the limited use of SCE methodologies supports this assumption.

2.4. Software cost estimation in industrial frameworks

Many of the commonly used project management frameworks, standards and other related guidelines address cost estimation. Project Management Institute's PMBOK Guide [19], as well as its Software Extension [51], give detailed guidance on preparing software cost estimates. Another popular framework, International Project Management Association's Competence Baseline [24], includes cost estimation as an important step. Furthermore, PRINCE2[1] and ITIL v3 [52] frameworks emphasize estimation and cost management, as well as the CMMI process improvement program [23] and the ISO 21500:2012 standard for project management [53]. Even the U.S. Government Accountability Office (GAO) published a 12 step guide for cost estimation[2]. Finally, cost estimation is also covered by agile methodologies [54].

[1] https://www.axelos.com/qualifications/prince2-qualifications

[2] http://energy.gov/sites/prod/files/GAO%2012-Step%20Estimating%20Process.pdf

3. Research questions

The literature review shows that SCE research has been centred on methodology for decades without a significant change. In contrast, PM research is very broad and covers topics such as methodologies, leadership and business. The focus of research also shifted from methodologies towards other areas, currently having a relatively even distribution on a broad range of topics. In particular, TMS was studied in the scope of PM but not SCE. Hence, though SCE and PM belong to software project delivery, the research focus is different. In the industrial context, the importance of SCE is widely recognized, and practically all major industrial bodies of knowledge provide guidance for cost estimation.

The above, together with the argument that proper cost estimation is often omitted [10, 36], suggests that the accountability of the use of meaningful estimation methodologies is unclear in organisations. There are no reports that SCE would be commonly omitted completely, rather that it is not conducted in a meaningful way. The previously reviewed project management and process improvement frameworks define clearly that project management is responsible for that the estimation is done, but not specifically that they would be responsible for how it is done. This seems to leave a gap in the software process, which may be one reason for malpractices and overruns. This motivates our first initial objective:

RQ1: What are the real-world factors concerning the organisational context of SCE (organisational factors) that either support or hinder the creation of a meaningful software cost estimate?

In our study, the organisational context refers widely to the properties and mechanisms of an organisation, such as top management commitment, leadership, organisational structure, communication, monitoring, recognition and education [55]. Effectively, the definition of the organisational context used in this study does not exclude any properties or mechanisms of an organisation, and we seek to identify the aspects affecting SCE that human subjects can or are willing to tell us about the topic [56]. Additionally, although the organisational context is the primary focus, biases emerging from human behaviour, as human subjects are centric for the organisational context, are also considered.

It has been found that technical issues are of little interest to senior managers [46, 47]. One reason for the existence of the previously described gap may be that SCE is perhaps perceived as too technical and too specific to software development to interest project managers. On the other hand, although software developers traditionally focus on technical topics and have little interest in or power over non-technical issues, they may not perceive SCE as a technical issue, and consider it as belonging to the project management's domain. Technical experts may also be protective of their domain in order to prevent loss of power to outsiders [57], while the suspicious and negative attitudes of senior managers towards IT and technical personnel [58] may hinder cooperation further. Therefore, the second initial objective of this study is to answer the second research question:

RQ2: What is the impact of top management in either supporting or hindering software cost estimation practices?

Finally, this paper draws attention to the difference between the extent of the use of SCE and PM methodologies, as well as to the different focus areas of research on SCE and PM. Additionally, the gap between the extensive amount of industrial advice on cost estimation and the low extent of the use of SCE methodologies is addressed. An enhanced understanding of the reasons behind these differences may help organisations improve their SCE success, positively affecting project success.

4. Case contexts

The topics covered in this paper have not been widely addressed prior to this study and our goal was to collect widely different perspectives related to the organisational phenomena affecting SCE, and especially top management's role. Thus, the cases were selected in such a way that

they would generate rich information about the phenomena being studied. The authors focused on large and small companies, selecting higher and lower maturity organisations and exemplary and challenged projects. The case companies and projects are different in their industrial domains, size, as well as in their processes. The final decision of including a particular project in the study was made based on a discussion with a company representative, confirming that the project was likely to add new perspectives in the study. Table 3 depicts the characteristics of the case study companies and the projects. The companies wished to remain anonymous.

4.1. Case 1 – Software Vendor's Tool project

Software Vendor is a software producing company of about one hundred and fifty people. Its main line of business consists of selling consultancy and support services as well as software products to businesses. The company is global and has offices in several countries. In this study the Software Vendor's Tool project, which aimed to produce an application development tool, was analysed.

While the overall project was strictly planned beforehand, the actual development work was divided into sprints. The development work started with a prototype version in which technical challenges were studied. The Product Owner and Project Manager were named to the project already in the prototype phase. The Product Owner was responsible for creating a design document for the product, whereas the Project Manager, based on the design document, was responsible for crafting a timetable and cost estimates. Initially, the project was designed to take three months with a team of four people. Based on the estimate and design document, top management approved and started the project.

The Tool project overran its schedule and budget by over 200%. However, the project delivered the planned scope and the Senior Business Manager reports that the outcome of the project met his expectations and he attributes the overruns to estimation error and project performance related issues.

4.2. Case 2 – service provider's operational control system project

Service Provider is a large software producing company with thousands of employees, providing tailor-made and package software, and consultancy services for businesses in various sectors. The company has premises in several countries. For the purpose of this research the Operational Control System project by Service Provider that aims to produce custom software for a long-term customer was studied. The Operational Control System is used for reporting and analysing process control data.

The project followed a Waterfall-like software development process. The first stage of the project was requirement elicitation and analysis. After the specification was approved, the project was estimated. The estimation was made by developers and testers, led by the project manager, who had the overall responsibility of the cost estimate. The estimate was a result of expert estimates, placed into a software tool specifically tailored for the application area.

The project was planned according to certain restrictions: the budget and the timetable was fixed. The development started when the customer and the vendor had agreed upon the scope. There was a small number of unknown features that needed further elaboration. The development work continued straightforwardly from design through implementation and testing to delivery. The duration and effort of the project was 10 months and 600 man-days, respectively. Regardless of a significant rescoping during the project, it concluded under budget and on schedule with good customer satisfaction.

4.3. Case 3 – Tech Giant's network management system project

Tech Giant is a large company selling products with software to global business-to-business markets. The company has tens of thousands of employees around the world. The Network Management System project of Tech Giant was analysed in this research. The project produced a new release of a tool for managing the network. The

Table 3. Case study companies and projects

Company	Software Vendor	Service Provider	Tech Giant
Number of employees	Approx. 150	Several thousands	Several thousands
Business area	Software and services	Software and services	Software and services
Project	Tool	Operational Control System	Network Management System
Initial/actual size of the project	12/44 person-months	20/20 person-months	Approx. 200/200 person-months
Initial/actual duration of the project	3/11 months	10/10 months	3/3 months
Project type	Internal product development	External product development, i.e. tailored software	Continuous internal product development
Estimation methodology	WBS and expert estimation	WBS and expert estimation, historical data, peer review	WBS and expert estimation, historical data
Estimation responsible	Project Manager	Project Manager	Program Manager
Development methodology	Scrumbut: Waterfall (design) + Scrum (sprints)	Waterfall-like method	Scrum
Result	Challenged	Successful	Successful

Network Management System has been in use for several years.

The project was a part of a continuous development cycle involving just under 100 people. A new release of the system is developed every three months. The development methodology it used was based on Scrum with two week sprints. The development teams were distributed over several locations. The cost estimation was conducted in two phases: firstly, rough planning for the whole three month release in the product management function. Secondly, the backlog items were estimated in the Scrum teams, the main responsible being the program manager. The estimate for the whole release was based on historical data about certain parts and the estimates for those parts were prepared by requirement engineers. The backlog items were estimated by using an expert estimation. The project concluded successfully and delivered over 85% of the planned scope, which is the goal for all releases.

5. Case study design

The question of how the organisational phenomena (RQ1) and specifically the actions of top management (RQ2) affect SCE are investigated through three case studies. Since this study deals with contemporary phenomena in a real-world context – over which the researcher has little or no control – the case studies were chosen as a suitable research approach [59]. This study is exploratory, discovering what is happening, seeking new ideas and generating hypotheses and research areas [60]. The research uses a multiple case study design and replication logic [59]. The richness of the information is maximised by using both exemplary and average organisations as cases [61]. The unit of analysis is a single software cost estimate. The study focuses on the experiences gained during the preparation of the cost estimate and the related software process.

To facilitate the identification of organisational phenomena, it was decided to utilise the concept of maturity. Software process maturity is the extent to which a specific process is explicitly defined, managed, measured, controlled and effective [62]. Paulk et al. [62] argue that maturity implies the potential for growth in capability and indicates both the richness of an organisation's process and the consistency with which it is applied in projects. Furthermore, mature organisations provide training for processes and the processes are monitored and improved. In

general, the concept of maturity measures organisational capability, culture and consistency in a holistic way, thus it can be expected to usefully facilitate the discovery of organisational phenomena. Thus the maturity of SCE and software processes are assessed for this study.

5.1. Instrumentation of SCE maturity

To assess the maturity level of SCE in an organisation, the definition of an ideal SCE procedure was developed, it covered its most important aspects as identified in [13]:

1. The use of an estimation methodology: A clearly defined, established estimation methodology is used to produce the estimate, instead of making presumptions.
2. Proper communication of the estimate: The assumptions, accuracy and intended use of an estimate are communicated as part of the estimate, instead of being presented as a figure lacking further explanation.
3. Planned re-estimation: An estimate is improved systematically when information about the assumptions behind an estimate is increased and updated after the initial estimate.
4. The use of a documented estimation procedure: A documented procedure for producing and communicating an estimate is followed, instead of an ad-hoc procedure.

If the above-mentioned areas of SCE are properly covered, the estimation process should avoid many of the worst pitfalls and the outcome will have a fair chance of being useful for project control. As demonstrated by Lederer and Prasad [63], using guessing or intuition as an estimation methodology is connected to budget and schedule overruns. Also, the accuracy of an estimate increases as a project progresses [64, 65], which encourages the re-estimation and good communication of an estimate. In addition, one poorly estimated aspect can become an *anchor* and may contaminate a whole project's estimate [66, 67]. Furthermore, a documented estimation procedure protects organisations from poor estimation practices and promotes good practices [13]. Standardised procedures have also been found to improve the results in PM [19, 68], specifically in software development [15, 69]. Thus, if an estimate is the result of a rigorous procedure covering the above mentioned aspects, it is more likely to be useful.

5.2. Instrumentation of process maturity

In order to ensure that the relevant phenomena are discovered, the scope of this investigation will be extended outside the actual SCE and assess the maturity of the software processes in the studied organisations by using the Capability Maturity Model (CMM) [62]. The CMM establishes a set of publicly available criteria describing the characteristics of mature organisations. CMM presents the process maturity of an organisation in a scale from 1 (low maturity) to 5 (high maturity). For the CMM assessment the general characterisations of maturity levels presented by Paulk et al. and [62, pp. 9–14] key software process area goals [62, pp. 59–64] are used. Together, the CMM characteristics and goals cover a wide range of process areas, so it is probable that reviewing these items will facilitate the discovery of organisational factors affecting SCE, helping to answer RQ1 and RQ2. While CMM is rather old, it still describes well the relevant properties and mechanisms of an organisation, making it a relevant tool for discovering phenomena in the organisational context.

Higher maturity organisations have been found to perform better in software development [70, 71]. The maturity assessment is also related to process areas rather than to techniques, to what rather than to how, making it agnostic to any specific development methodology. Therefore, the software development and estimation maturities are relevant to the discussion of organisational phenomena. The CMM is also specifically intended to be used for software process assessment and software capability evaluations [62].

The CMM evaluation for the case study companies was made by the researchers during the interviews and documentation review. We would like to point out that we followed good auditing practices and the main author had over five years of experience of auditing and holds an ISO

9001:2008 Lead Auditor certificate. Therefore, we believe that the CMM requirements conformance evaluations conducted as part of the research are valid and we gained a good overall understanding of an organisation's CMM level, even though the focus was still primarily on SCE. In this study the main interest were SCE related topics and CMM acted only as a facilitating instrument.

5.3. Subject selection

The subject sampling strategy was to interview the management and representatives about other roles related to the case projects. In total 15 people were interviewed in 18 interviews (key informants were interviewed twice), as presented in Table 4. All participants attended interviews voluntarily and anonymously and the collected data is treated confidentially.

5.4. Data collection procedures

The data for this study was collected within seven weeks. The primary data collection methods were semi-structured interviews [60] and a review of documentation. In total 15 people were interviewed and 18 documents reviewed. The documents included typical project documentation, such as cost estimates, project plans, meeting minutes and status reports, to gain a better understanding of the procedures and SCE methods used. The case studies were completed one at a time to allow the reflection and refinement of the research and interview questions [72]. All the interviews (but not key informant interviews) related to a single case study were conducted on the same day, with the exception of one interview for the last case study. Each interview lasted approximately one hour. Each interview day was preceded by a key informant interview day during which background information about the case was collected from a person in a central role in the case study area. The key informant interviews addressed the following topics:

1. Project background, size, status and success.
2. Project team members and their roles.
3. Estimation methodology and success.
4. Software development methodology.
5. Software process maturity, capabilities and track record.

The semi-structured interviews were based on a predefined list of questions. Any interesting facts and observations that were mentioned led to additional questions being asked on that subject. The interview instrument was developed by three researchers and adapted slightly for the individual case studies. All the interviews were conducted by two researchers, who interviewed one subject at a time. The interview instrument is provided in Appendix A, it consists of the following main areas:

1. Introduction.
2. Personal, team and project background.
3. Current state of SCE in the organisation.
4. Experiences of the organisational phenomena affecting SCE.
5. Ending (uncovered topics).

5.5. Data analysis procedures

The primary steps for deriving conclusions from the experiences of the study subjects included 1) semi-structured interviews, which were sound recorded, 2) collection of documentation, 3) transcription of the interviews, 4) the coding of transcripts and documents, 5) grouping the coded pieces of text, and 6) making conclusions. The NVivo 10 application was used for aiding the process, and special care was taken to maintain a clear chain of evidence. The overall process of analysis was conducted as outlined by [73].

During the coding phase, each interview transcript and collected document was reviewed statement by statement, and statements containing information about organisational factors (RQ1) or top management participation (RQ2) were assigned a code representing the findings category. After that, readily coded main categories were reviewed statement by statement to identify subcategories. The subcategories were also identified from the original transcripts. After a couple of iterations, the subcategories emerged from these two approaches. The performed analysis was of the inductive type, meaning that the patterns and categories of the analysis come from the data, instead of being pre-defined. Themes that

Table 4. Interviewees and their role in the projects

Software Vendor	Service Provider	Tech Giant
Product Owner (key informant)	Project Manager (key informant)	Program Manager (key informant)
Senior Business Manager	Business Manager	Line Manager
Senior Technology Manager	Testing Manager	Senior Manager
Project Manager	Requirements Engineer	Requirements Engineer
	Software Developer	Head of Product Management
		Head of Programs

were often raised in the interviews were identified and coded. The application used for coding (NVivo 10) maintained the evidence trail from the coded pieces of text back to the documents, transcripts and interviewees automatically. The coding of the texts was primarily conducted by one of the researchers. Another researcher conducted a shorter coding of the data, with fewer iterations, independently, to validate the results of the coding. Any differences were discussed and resolved, and the categorisation was refined. The final categorisation formed a structure for reporting the findings of the study.

After the coding of the data, the coded statements were grouped together to form initial hypothesis, or candidates, for conclusions. The process progressed iteratively, and was, once again, conducted primarily by one of the researchers, while another researcher conducted an independent analysis with fewer iterations to validate and refine the results. After a certain number of iterations, and until the end of analysis, the analysis of the statements was conducted by two researchers together. The other two researchers reviewed and validated the results. During the process of forming a hypothesis, interviewees were asked clarifying or additional questions, where deemed necessary, to resolve any unclarities and to provide additional confidence for the hypothesis. The traceability was secured by marking all statements used for forming the hypothesis with identification codes, enabling back tracing to the coded statements.

In addition to the interview data and documentation, the researchers' memos written during the interviews were used as information sources and as part of the data analysis. The collected project documentation provided mostly background data for the case projects, and to some extent, information regarding top management's participation in different phases of the projects. From the organisational context point of view, the documentation provided some information about the software process and related decision making. The role of the collected documentation was mostly to provide background information and to support statements made by the interviewees.

5.6. Validity procedures

The qualitative case study methodology involves the researchers themselves as the instrument of the research, which poses a risk that the results are biased by the researchers' subjective opinions. More generally speaking, Robson [60] identified three types of threats to validity: reactivity, researcher bias and respondent bias. Reactivity means that the presence of the researcher may influence the study, and particularly the behaviour of the study objects. Researcher bias refers to the preconceptions of the researcher, which may influence how questions are asked and answers are interpreted. Finally, respondent bias originates from the respondents' attitudes towards the research, which may lead, for example to withholding information or giving answers the respondents think the researcher is looking for.

Because of the researcher related threat to validity, a discussion of the effects of the involvement of particular researchers is appropriate [60]. The main author of this article has been involved in professional software development since 1996, including companies from start-ups to international giant corporations. Additionally, he has been con-

ducting academic research within the area of SCE since 2012, holds an ISO 9001:2008 Lead Auditor certificate, and has over seven years of experience of quality management system audits. The other authors are from academia, having their main focus in software process, software development methodologies and software economy. Together they have published hundreds of research papers, and used different methodologies extensively in their research, including qualitative case studies.

The reactivity, researcher bias and respondent bias threats to the validity of the study were addressed through six strategies provided by [60]: prolonged involvement, triangulation, peer debriefing, member checking, negative case analysis and audit trail. The summary of the taken countermeasures to negate the validity threats are summarised below:

Prolonged involvement: While the study observations were completed during a short period of time, all the researchers had followed the case study companies for at least two years and were intimately aware of recent developments in the software development methodologies being used. All case organisations had participated in a national research programme, Need4Speed (www.n4s.fi), enabling the confidential sharing of information between the organisations and the researchers.

Data source triangulation: Multiple data sources were used, including interviews with persons in different roles, project documentation and informal observations.

Observer triangulation: Interviews were conducted by two researchers together. This also reduced the strain caused by conducting up to six interviews during one day. Additionally, the interviewees had a short break before each interview, and a longer break in the middle of the day. Important analysis steps were conducted by two researchers independently, and emerging issues were discussed and refined.

Methodological triangulation: The data analysis included qualitative interviews and the analysis of project documentation.

Theory triangulation: Several perspectives were considered for interpreting the results, including the perspectives of the subjects, researchers and other peer group members.

Peer debriefing: Peers, including practitioners and researchers, reviewed the research in different research phases. One research paper based on the conducted research has already been published [17]. The results of this research have been reviewed by the Need4Speed research programme steering group.

Member checking: Interviewees reviewed both transcripts and analysis, providing feedback and commentary.

Negative case analysis: Elements that seemed to contradict the conclusions of the analysis were identified and alternative explanations discussed.

Audit trail: Strict scrutiny was practiced to maintain a clear audit trail from data collection to the final conclusions. All interviews, transcripts, codings and other analysis are archived.

Considering that this study is based on three projects, exploratory of nature, and that the study topic has not been widely explored prior to this study, *generalizability* of results is low. However, the study consists of three case companies and 15 interviewees with different roles, and it provides in-depth findings and detailed information of the study itself. Thus, *transferability* of the study should be fair, although case studies are always coloured by their specific context.

6. Results

The following sections present the findings related to organisational phenomena (RQ1) and top management actions (RQ2) affecting SCE. The findings are divided into four main categories (the role of management, communication, process maturity and attitudes) that were found in the analysis and classification of the results by the authors. Additionally, the main categories are divided into subsections as appropriate. The main observations related to the second research question are located in Section 6.1 whereas the sections 6.2–6.3 contribute the first research question.

Table 5. Summary of management role findings

	Case 1	Case 2	Case 3
Company Project	Software Vendor Tool	Service Provider Operational Control System	Tech Giant Network Management System
Estimate purpose	Ensuring the resources, scope and schedule balance, ensuring the minimum viable scope and fast delivery	Preparing an offer for a customer	Ensuring the resources, scope and schedule balance
Participation in estimation	The project plan containing the estimate studied at a summary level, management not aware of the estimation practices	The estimate reviewed on a summary level, management aware of the estimation practices, the project manager scrutinized the estimate	The estimate reviewed on a summary level, management not aware of the estimation practices, the product owner scrutinized the estimate
Resource provisioning	Estimators had enough time for preparing the estimate, prototypes used for supporting estimation	Estimators had enough time for preparing the estimate	Estimators wished to have more time, prototypes used for supporting estimation
Demonstrated importance	Estimates considered as important, confirmed by interviewees	Estimates considered as important, confirmed by interviewees, importance linked to customer promises	Estimates considered as important, confirmed by interviewees, importance linked to customer promises
Goal setting	Goals perceived as realistic, realism pursued, no support for realism from historical data, clear expectations of the scope and schedule, pressure to fit the estimate to expectations	Goals perceived as realistic, realism pursued, hundreds of annually delivered projects supported realism	Goals perceived as realistic, realism pursued, four annual releases for the same product supported realism
Other	No shared project vision		

6.1. Management role

Findings related to the management's role are presented in the following sections.

Table 5 summarises the findings.

6.1.1. Estimate visibility and purpose

In Case 1, the Tool project, Senior Business Manager studied the project plan containing the estimate considering the strategic importance of the project to the company. In Case 2, the Operational Control System project, the business manager responsible for the important customer relationship reviewed the estimate. Practically, the visibility of the estimate correlated with the ownership of the project and the daily involvement of the managers with the project domain. There was no visibility of the estimate beyond the review as the project was no longer part of the manager's daily responsibilities. In Case 3, the Network Management System project, the most senior manager aware of the estimate was the manager of the whole product family. There are roughly 1,000 experts involved in the system development, so the estimate was visible to relatively senior managers.

In Case 2, the estimate was used for preparing an offer for a customer and planning the project, while in Case 1 and Case 3, the managers reported that they needed the estimate to ensure that the resources, scope and schedule were in balance with each other. In Case 1, the Senior Business Manager reported that the estimate was needed to ensure the project scope was the minimum viable and that the project would deliver the results as soon as possible.

6.1.2. Participation in estimation

None of the managers studied the estimate in detail. In Case 1, the Senior Business Manager reviewed the estimate only as part of the project plan. In Case 2 and Case 3, the managers reviewed the estimates on a summary level. None of the managers participated in the estimation work, and the managers in Case 1 and Case 3 were not aware of the estimation practices. In Case 2, the manager was aware of the practices because cooperation with the customer was said to be very intense; the customer wanted to discuss processes related to daily cooperation. While the managers were not involved in estimation on a practical level, the managers in cases 2 and 3 stated that they challenged the estimate when necessary. Also, in these two cases, the Project Manager and Product Owner, respectively, scrutinized the estimate. An awareness of such scrutinizing allowed the managers to have greater trust in the estimate. That is, there was no need for them to personally study the estimate in detail.

6.1.3. Resource provisioning

In Case 1 and Case 2, the Tool and Operational Control System projects, the estimators reported that they had enough time to prepare the estimates. In Case 3, the Network Management System project, the estimators wished to have more time. However, although the estimation work was very time consuming and complex, when considering the previous good results, the time reserved for estimation seems to have been reasonable. The perceived lack of time was connected to the complexity and size of the estimation domain. Also, an estimator in Case 3 wondered whether additional time would actually improve the estimates. In Case 1 and Case 3, building prototypes was also used as a method for acquiring additional information to use for estimation, which supported the idea that management provided adequate resources for the estimation work.

6.1.4. Demonstrated importance

In all cases the projects had strong support from management, and the managers emphasized the importance of the estimates. In Case 2 and Case 3, the estimate was strongly linked to keeping the promises given to customers. All the interviewees concurred that management considered the estimates to be of high importance.

6.1.5. Goal setting

All interviewees reported that the project goals seemed realistic and achievable at the beginning of the project, and that everybody pursued realistic estimates. In Case 2, Service Provider delivers hundreds of projects yearly, while in Case 3, Network Management System has four releases per year, thus its management is likely to have a realistic picture of its organisational performance. This probably also supports the setting of realistic and achievable goals for releases and projects. In Case 1, the Tool project was using a new development methodology for the first time, meaning relevant historical data about the process performance was lacking and goal setting was unsupported.

In Case 1, Senior Business Manager expressed the strategic importance of the project, which he had initiated personally, prior to the estimation. Also a roadmap vision, which presented a release date, had been communicated for the product. Furthermore, the scope of the project was considered to be the minimum viable, meaning that the scope could not be reduced. As a result, the estimator was facing a situation in which both the scope and schedule were effectively set, which is always a challenging situation from project planning point of view. The estimator describes having perceived pressure to fit the estimate to

these expectations and having started to doubt the estimates when they did not match initial expectations. Case 1, the Tool project, thus seems to have experienced the anchoring phenomena [66, 67], i.e. the estimate is affected by an expressed starting point. However, Senior Business Manager of Case 1 points out that flexibility in resources and schedule was emphasised prior to estimation.

6.1.6. Provided direction

The interviewees in Case 1 report that there were different expectations for its outcome: Senior Business Manager expected a strong commercial product, while others were building a pre-version, which would contain the full scope of features but not on the quality level expected of a commercial product. The expectation of the rest of the team was that the quality issue would have to be addressed in the next version of the product. This difference in the expectations was probably a significant source of estimation error. Actions for error detection and customer feedback collection add to the amount of work required, as do fixing bugs and improving functionalities based on customer feedback.

6.2. Communication

The role of the written documents, as required by the processes, was significant in Case 1 and Case 2, which followed Waterfall-like development methods. The projects had significantly invested in preparing the documents on which the estimates were heavily reliant. Interviewees from both projects reported that the documents were detailed and of high quality. Also the Network Management System team in Case 3 used documentation as part of its estimation but – as is typical of agile development – it did not have an official role. The documents were prepared on demand when necessary, including pre-studies, memos, presentations and user stories. In addition to the documents, Software Vendor in Case 1 had developed a prototype to get more information on the application area. Prototypes are artefacts, which are likely to support successful estimation because they contain significant amounts of relevant information on the estimated application area and answer many questions relevant to estimation [74]. Tech Giant in Case 3 also reports that it occasionally uses prototypes, while the Business Manager from Service Provider adds that prototypes would be useful but are not utilised at the moment.

While the interviewees recognised the importance of the written documents, all the interviewees in Case 2 and Case 3 emphasised that the process of preparing an estimate is more important than the result itself. The Requirements Engineer and the Project Manager in Case 3 describe the importance of mutual understanding, and all reported that truly understanding each other's needs is crucial. The Requirements Engineer pointed out that estimates become ever more reliable through discussions and said that he is satisfied when all the questions are answered. The Requirements Engineer also highlighted the fact that working together provides confidence in each other. Group estimation sessions were used regularly in both Case 2 and Case 3. The Senior Manager in Case 3 concluded that a good estimate is based on good skills in preparing the specifications and having a broad knowledge about the application area and software development – the majority of the Network Management System project team members in Case 3 had worked on the product for five or more years. Communication seems to be central to estimation in Case 3 because issues like multiple locations and time zones hindering estimation were mentioned. Agile grooming was also mentioned as an important forum for estimation and related communication.

In Case 2, the Project Manager and Testing Manager reported that good cooperation and fact based communication with customers supported estimation. They also emphasised the role of feedback. The interviewees at Case 2 described team members as competent in their area of expertise, stating that estimates were prepared together to a large extent. The Testing Manager added that the atmosphere was open in general. Peer estimation was used on both the programming and PM level. The Project Manager stated that being

able to receive consultation or a peer review from another project manager is more important than using information systems to support estimation. The Business Manager added that the project's estimation succeeded because they understood the customer's needs. The Software Developer expanded on that by saying the estimation succeeded because all the details relevant to the case were found. The Testing Manager described an estimation as meaningful if the right experts were consulted and involved in discussions.

In Case 1, the communication relied more on the documentation. The project manager who prepared the estimate described it as being stored on a shared folder, although no feedback was received. The estimate was based on a design document, which was prepared by the Product Owner. The Project Manager revealed that there had been some discussions with the Product Owner to scope down certain features but the Product Owner and the Senior Technical Manager reported that the estimate had not been challenged at any phase. However, they both stated that they had been sceptical about the estimate but could not point out exactly where the problems resided, and therefore did not raise their reservations. In general, the interviewees reported very few occasions when the estimate would have been discussed. The communication relied mostly on documents prepared by individuals. However, the Senior Technical Manager and Product Owner reported that the atmosphere was open and there was no pressure not to discuss a topic.

6.3. Process maturity

6.3.1. Estimation maturity

All of the case study companies had a documented software process describing how estimation was related to the whole and which documents were required, but only Service Provider in Case 2 had a written procedure for the estimation itself. However, Tech Giant in Case 3 had established estimation procedures, although not documented. Service Provider (Case 2) and Tech Giant (Case 3) had used the same practices for several years, whereas this was the first time for Software Vendor (Case 1) using the estimation procedure in question. The interviewees at Tech Giant and Service Provider reported that they had a history of making successful estimates, while the interviewees at Software Vendor stated that they tend to underestimate and have a poor track record in estimation.

The progress of the project was monitored from the estimation point of view in all case projects. In Case 1, the estimate was presented as a single point estimate. In Case 2, the estimate was presented as a range, consisting of an optimistic, pessimistic and nominal scenario. In Case 3, the target was to deliver at least 85% of the nominal estimate, which can also be seen as a range. The actual project team was more or less known in all projects at the time of estimation. The interviewees in Cases 2 and 3 report that the general estimation capabilities are good, emphasising the importance of professional competence in estimation. The interviewees in Case 1 reported that their estimation capabilities and experience are low. There has also been training related to estimation practices in Case 2 and Case 3. In Case 2, at Service Provider, there was a named person who was responsible for developing estimation practices, which was not the case at the other two companies.

Applying the CMM scale from 1 (low maturity) to 5 (high maturity) and related behavioural characteristics [62, pp. 9–14] to SCE maturity, Service Provider (Case 2) was assessed as being on the highest level, level 5. Their estimation procedures produce reliable results, which are adjusted to specific application areas and technologies and there is systematic work to improve estimation practices. According to our assessment, Tech Giant (Case 3) is on level 4, meaning that while there is room for improvement, the standard processes are defined and established and produce reliable results. Finally, Software Vendor (Case 1) is on level 2, meaning that the processes are defined and may support the production of consistent results. However, in practice, the process discipline was low and the defined practices cannot be applied in real-world situations consistently and successfully.

Table 6 summarises the findings on the SCE procedures used in our case projects; categorised according to the SCE capability criteria defined

in Section 4.2. The SCE maturity, when set against the criteria in Table 5, seems to correlate well with the CMM maturity levels and the related behavioural characteristics: Service Provider and Tech Giant have practices in place for repeating processes and gaining predictable results. This issue will be discussed more in Section 6.1. There was no standard practices that support the development of consistency at Software Vendor.

6.3.2. Software process maturity

In Case 1, the process used for Tool was relatively new, implemented in the first half of 2014, and was followed by an organisational change in the second half of 2014. The company was adopting Scrum methodology and abandoning the process used in the case project. The Senior Technical Manager of the company said that the primary focus has always been on programming at the cost of other things, such as leadership and PM. The interviewees also referred to similar overruns in projects resembling Tool.

In Case 2, the project manager reported that they deliver hundreds of projects yearly using the same delivery process as used in the case project. The processes are stable and under constant development. According to the Project Manager and Business Manager, the results have been generally good, which was also true of the case project. There was also a training related to the different aspects of the software project delivery model.

Also, Tech Giant in Case 3 has used the current Scrum based process for approximately seven years. According to the Line Manager, the process was under constant development, which was supported by comments from other interviewees. However, the two representatives from product management report that there is still much room for improvement, especially regarding the basing of estimates on current data instead of historical data and the managing of dependencies. Regardless of the pointers for improvement, the product management representative, and other interviewees, described the overall software development performance as good.

To recapitulate, according to our assessment of the overall software process maturity, Software Vendor (Case 1), Service Provider (Case 2) and Tech Giant (Case 3) are on the CMM levels 2, 5 and 4, respectively. A summary of the assessment findings is presented in Appendix B.

6.3.3. Attitudes

All the interviewees in this study recognised the importance of estimation. The reasons for the experienced importance varied. In Case 3, the Senior Manager argued that estimation facilitates the planning process before the actual work, connecting work to reality. In Case 1, the Project Manager stated that estimation is important from the planning perspective and the Testing Manager in Case 2 concurred. Nevertheless, estimation was experienced as a high importance one. In all case projects, the project manager had the overall responsibility for preparing the estimate. All of the project managers reported that their commitment to the estimate was high.

In Case 1, the general attitudes towards estimation were negative. For example the Senior Technical Manager, Project Manager and Product Owner argued that estimates were not trusted because they were likely to fail. The Senior Technical Manager stated that people were indifferent to the estimates because the usual reaction to overruns was just to continue the project. The Project Manager reported that he did not like giving an estimate and was afraid that the estimate would be interpreted as a commitment. During the re-estimation of the functionalities, the Project Manager described having given upper-bound estimates due to the high level of uncertainty, which also led to the implementation team's reluctance to estimate.

In Case 2, the Customer Manager describes the general attitude towards estimation as good and all the other interviewees agreed, reporting that estimation was a meaningful and motivating task. However, the Testing Manager and Software Developer report that when they are asked for quick and rough estimates, the work does not feel meaningful. They felt that some experts in

Table 6. Summary of SCE capability findings

	Case 1	Case 2	Case 3
Company Project	Software Vendor Tool	Service Provider Operational Control System	Tech Giant Network Management System
Use of an estimation methodology	(−) No defined standard practice	(+) Work break-down, historical data, software tool	(+) Agile grooming, work break-down, historical data
Proper communication	(+) Assumptions presented (−) Single point	(+) Assumptions presented, range	(+) Assumptions presented, range
Re-estimation and follow-up	(+) Regular follow-up	(+) Regular follow-up	(+) Regular follow-up
Documented estimation procedure	(−) No documented or established procedure	(+) Documented procedure adjusted for the application area, improved continuously	(+) Established, but (−) Not documented
Other	(−) Short experience, low competence, poor track record	(+) Long experience, high competence, good track record	(+) Long experience, high competence, good track record

their company, at Service Provider, take estimation too lightly, not necessarily recognising it as demanding and important work, although the importance of an estimate is understood by all. The Project Manager commented that estimates are sometimes given reluctantly because they are then interpreted as commitments. The Requirements Engineer reported that estimation was not necessarily a pleasant task due to its difficulty. However, the interviewees agreed that estimation generally worked well.

In Case 3, the Requirements Engineer and Project Manager stated that estimation was not a pleasant task, though the discussions are seen as meaningful and relevant. Like the two interviewees in the Operational Control System project, the Requirement Engineer in the Network Management System project said making quick, rough estimates was not motivating. The Line Manager noted that estimators may be afraid that the estimates may not be as desired or that inaccurate estimates will lead to re-planning and corrective actions in the later phases of a project. Estimating was seen as an onerous responsibility. The Senior Manager commented that the development organisation should improve their estimation practices in order to improve the accuracy.

7. Discussion

The following Section 7.1 presents the key findings of this study. The remainder of this section will present the academic (Section 7.2) and practical implications (Section 7.3) of this study, addressing the study's limitations and giving pointers for future research (Section 7.4).

7.1. Key findings

This study focused on gaining insight into top management's role in SCE and discovering organisational phenomena that either support or hinder successful SCE. There were two main research questions: (RQ1) What are the real-world organisational factors that either support or hinder the creation of a meaningful software cost estimate? (RQ2) What is the impact of top management in either supporting or hindering software cost estimation practices?

The primary findings of the study are summarised in Table 7. It was demonstrated that communication, attitudes and process maturity seem to support and hinder the creation of meaningful SCE (RQ1). Furthermore, top management's support and realism were found to support the results of SCE, although anchoring and

the lack of a shared project vision were found to hinder SCE (RQ2). Finally, many of the factors affecting SCE, such as communication, providing resources and shared vision, have been found to affect project execution as well. This overlap is natural, since both SCE and project execution are inseparable parts of a software project. Our study, however, focuses on SCE influences, and presents evidence on factors affecting SCE specifically.

7.2. Implications for theory

It has been argued that only a very few papers examine the organisational context of SCE and how its methodologies are applied in real-world situations [14]. According to Jørgensen and Shepperd [14], the basic problems experienced by software companies in relation to SCE are not technical. Hence, this paper has specifically focused on the organisational context related to SCE and in increasing the understanding of the prerequisites for meaningful SCE. This paper also demonstrates that SCE research remains focused on technical issues, while the focus of PM research has undergone a major shift from a technical to a managerial focus.

The primary finding of this study is that there seems to be a connection between the software process maturity, estimation maturity and estimation success. The maturity as a construct consists of several factors. This study did not identify individual significant organisational factors, which alone would make estimation successful. The connection between the maturity and estimation success suggests that successful estimation is a sum of several factors, such as communication, competence, experience and attitudes.

The more specific results from this study show that commonly used estimation techniques, WBS and expert estimation, can produce good results, if the overall project management and software practices are established and produce consistent results. This paper also suggests that communication is an important factor in the scope of SCE. Furthermore, the findings suggest that SCE should not set any specific requirements for top management, other than that they should carry out their basic responsibilities effectively and avoid the harmful anchoring of estimates.

The finding of this study also correlate well with the previous studies in the area of organisational context and human factors. From the organisational context point of view, Magazinovic and Pernstål [10] researched causes for estimation error, also validating results of Lederer and Prasad's [75] earlier study. They found that management goals affect the results of estimation. This seemed to happen also in Case 1 of this study. Also, in the same study, they found that unclear requirements are a source for estimation error, and that organisations do not have guidelines for conducting cost estimation. Case 1 suffered from unclear requirements, and Case 1 and Case 3 did not have guidelines for estimation. Furthermore, Magazinius, Börjesson and Feldt [9] found that personal agenda, management pressure and attempt to avoid re-estimation may affect the estimate. This seemed to be the case also in the Tool project of this study. The promotion of the project [76] may also explain parts of the tight target setting for the Tool project.

Cognitive bias is another non-technical topic related to SCE, which has gained attention recently. While the primary focus here was in the organisational context, it was discovered the presence of anchoring [66] in Case 1. There also seemed to be, at least to some extent, an attitudinal tendency in all cases to find hindrances for estimation outside the respondent's direct influence, corresponding with [77].

Based on the results presented above, this paper supports the assumption that the estimation challenges experienced in companies are not only technical, but are also related to the organisational context, specifically to the project management and software process maturity. Also, easy to use estimation techniques may not be used by chance but because of the fact that these methods require less organisational capabilities for their successful application. These findings, along with similar findings, should justify SCE researchers shifting their research focus from technical topics to managerial and processual ones.

Table 7. Summary of findings from the case projects by category

	Case 1	Case 2	Case 3
Company	Software Vendor	Service Provider	Tech Giant
Project	Tool	Operational Control System	Network Management System
Outcome	Challenged	Success	Success
Management role	(+) Strong support, realism pursued, enough resources (−) Anchoring, no shared project vision	(+) Strong support, realism pursued, enough resources	(+) Strong support, realism pursued, enough resources
Communication	(+) Detailed plans and specifications, prototype (−) Estimate prepared by one person, lack of discussions and cooperation	(+) Detailed plans and specifications, mutual understanding and insight pursued, cooperation intensive process, expertise and competence emphasised, shared project vision	(+) Aide memoir documentation, mutual understanding and insight pursued, cooperation intensive process, expertise and competence emphasised, shared project vision
Process maturity	(+) Documented software process, regular follow-up (−) No documented estimation procedure, non-established processes, no continuous improvement, no training arranged, low estimation experience and competence, no historical data used	(+) Documented software process, documented estimation procedure, established processes, continuous improvement, training, historical success, high estimation experience and competence, estimate as a range, regular follow-up	(+) Documented software process, established processes, continuous improvement, training, historical success, high estimation experience and competence, estimate as a range, regular follow-up (−) No documented estimation procedure
Attitudes	(+) Importance recognised (+) Project manager commitment high (−) Generally not pleasant, generally negative attitudes, indifference to failure, reluctance	(+) Importance recognised, estimation regarded as meaningful and motivating, general opinion that estimation works well (+) Project manager commitment high (−) Quick, rough estimates not motivating, sometimes unpleasant because of difficulty, some people do not recognise its seriousness, estimates interpreted as commitments	(+) Importance recognised, discussions regarded as meaningful and motivating, general opinion that estimation works well (+) Project manager commitment high (−) Generally not pleasant, quick, rough estimates not motivating, estimates interpreted as commitments, fear of failure, some reluctance

7.3. Implications for practice

This study addressed the top management's role in software cost estimation. In the following, we will discuss the practical advice found in this research. These are categorized into four groups: top management's role, the importance of communication, organization's process maturity and general attitudes towards SCE.

7.3.1. Top management role

This study suggests that by supporting SCE through the basic TMS practices found in this study, demonstrating SCE's importance, reviewing plans, providing resources and ensuring a shared vision and commitment, top management can create an environment for successful SCE. Earlier studies support this conclusion. For

example Boonstra [78] has found that the provision of resources, the establishment of a clear and well defined project framework, communication with the project team, being knowledgeable about a project and using power to resolve conflicts are important behavioural categories for top management. Zwikael [25] has reported similar findings, and concludes that, e.g. an organisational structure that is supportive of a project, communication between the project manager and the organisation and appropriate project manager assignment have a positive impact on project success. However, the previously defined behaviour is likely to be enough only in an environment where management has already created the necessary capabilities and gained the required experience for successful software work.

On the other hand, the results indicate that if there is a lack of a shared vision or a lack of commitment, the negative impacts on SCE can be significant. This finding receives support from earlier studies. White and Fortune [18] report that 'Clear goals/objectives' was the most frequently mentioned success factor for projects. Fortune and White [40] report that 'Clear realistic goals' was the second most cited factor for success. However, clearly expressed expectations may also become harmful anchors and distort SCE, as found in this and other studies [66, 67].

In summary, successful SCE seems not to require any specific actions from top management, if the general maturity of a work environment is good. Thus, it is enough if management performs its role effectively by providing typical TMS behaviour. However, top management should avoid situations in which their expectations could become anchors that negatively affect SCE.

7.3.2. Communication

The results provide evidence that communication related issues are important factors in successful SCE, when work breakdown structure (WBS) and expert estimation are in use. In both of the successful projects, Cases 2 and 3, the interviewees reported that mutual understanding and understanding the requirements were sought by management. Furthermore, there were many opportunities and forums for discussions on the issues. Hence, cooperation was described as good and the expertise as sufficient for reaching an adequate level of understanding.

There are plenty of similar findings from other areas related to the importance of communication. In the scope of project cost management, [31] it was found that early interaction with key stakeholders and the establishment of clear lines of communication for sharing professional and project based knowledge are crucial during the inception phases of projects. Furthermore, the significant role of communication in managing the coordination process was addressed by Malone and Crowston [79]. Communication was found to be a common success factor when discussing change in software projects and teams [80] and the best way to build trust in development teams [81]. Communication was also found to make software development more efficient in companies [82] and was shown to be one of the cornerstones of agile development [83]. In the scope of SCE, Jørgensen [77] noted, in a case study, that poor communication skills or team dynamics might have had an impact on the SCE's result in one team.

On a practical level, these findings suggest that project managers, software professionals and other project team members should focus on achieving an understanding of requirements through discussion, instead of focusing on compliance, techniques and documentation.

7.3.3. Process maturity

All of the case projects used easy to implement [84] estimation methodologies, such as WBS, expert estimation and group estimation. The methodologies seem to produce useful results in a mature environment. Established processes and at least moderate maturity seem to be the key to successful application of estimation methodologies. This conclusion also receives support from earlier research. The success of expert estimation has been shown by Jørgensen [85] and studies on the impact of CMM levels on estimation results show that companies who have levels from three to five produce significantly more accurate re-

sults than companies on the lower maturity levels [13, 86, p. 10]. However, although the estimation accuracy and CMM level seem to correlate with each other, we would like to point out that there seems to be no significant correlation between the project management maturity (PMM) of an organisation and the project success [87]. The correlation between the CMM level and estimation accuracy observed in this study occurs within the studied area of maturity, SCE being part of the software process maturity.

Maturity as a construct consists of several factors, like experience, skills and processes. While we report several maturity related findings connected to successful estimation, like training, experience and continuous improvement, we believe that none of the individual factors is likely to lead to success on its own. However, a lack of one of those factors may have significant negative impacts. Thus, based on our findings, we decided to focus on maturity as a whole, instead of individual factors.

Software process maturity (or project management maturity), estimation maturity and attitudes seem to have a clear interrelationship. If software process maturity is good, estimation maturity seems to be good, furthermore attitudes become more positive. This is not surprising, because SCE is part of a software project and managed under the relevant software project or software process management. The CMM model does not include attitudes in its attributes, although, for example, [88] suggest attitudes are an important factor in project management maturity, in addition to knowledge and action. However, the true relationship between these three is beyond the scope of this study.

Considering the previous and the findings presented in Table 7, it seems intuitive that the overall maturity correlates with the estimation success. This is supported by Flowe and Thordahl [86] and findings from Boeing, presented by McConnell [13, p.10]. Furthermore, each of the elements of maturity is likely to contribute to estimation success also individually. For example Jørgensen [85] has provided evidence that training opportunities, good estimator competence and use of an estimation checklist improve estimation success. In other words, the more there are elements of high maturity present, the higher is the probability of estimation success, and vice versa, low presence of high maturity elements increases uncertainties in estimation.

Our advice for organisations would be to include a simple maturity self-assessment in the software cost estimation process, for example based on a publicly available criteria like CMM or CMMI. If the maturity is assessed to be low, a thorough uncertainty analysis is appropriate. Even the knowledge of high level of uncertainty may help managers in their decision making, even though the uncertainties could not be mitigated. Also, we understand that self-assessments are perhaps not typical for low maturity organisations. However, the use of a simple maturity assessment is far easier than accounting the whole industrial and scientific body of knowledge as individual items. In the beginning, the awareness of the high level of uncertainty could help to make better decisions, and in the longer term act as a list of development pointers towards higher maturity.

For the practitioners in higher maturity organisations, it would be recommended to address specific estimation challenges, like estimating change requests or estimating testing. For example, those two areas seem to be sources of errors [11] and serve to decrease motivation, even in exemplary organisations. Also the relationship between the estimate, target and commitment is not always clear, which was reported as resulting in a reluctance to make estimates; the importance of making a distinction between these three aspects is addressed by McConnell [13].

7.3.4. Attitudes

In cases 2 and 3, project managers had the overall responsibility of preparing the estimate, while the actual estimation was done by software developers. In both projects the estimation was seen as an important and relevant task, and the project managers reported that they were committed to the estimates.

However, in both projects the developers' attitudes towards estimation were negative. Estimation was not considered as a pleasant task and

reluctance and low motivation were reported, especially originating from lack of trust and quickly emerging needs requiring flexibility. Negative attitudes, low motivation and reluctance have been found to decrease the quality of work [89]. Although estimates and outcomes have correlated well in these two projects, it is likely that the risk of estimation error increases when negative attitudes are present, especially in low maturity organisations. Trust and flexibility as values have been found to have a positive effect on project outcome [90]. A trivial advice is to support a positive atmosphere around estimation. However, further research is needed to provide better and more specific advice on this topic.

7.4. Limitations and future work

Although a number of countermeasures to validity threats were taken (see Section 5.6) and the transferability of the results was improved by collecting a rich set of data, this research has certain limitations. This research considered the organisational phenomena at a general level, without taking the project or organisation specific characteristics, like development methodology or company size, into account in the study design.

The findings provide evidence that, at a general level, organisational issues, like the role of management, process maturity and communication, are important factors in SCE. However, although we believe that the results are transferable to similar project settings, the organisational challenges may vary between different contexts. For example, some organisational properties or mechanisms may have been overlooked, such as the size of the company, which causes variation between projects. In addition, there are different reasons for the cost estimates: one company was using them to set the price to the customer while the others were seeking balancing content and timing of their products with the estimates.

Therefore, we encourage further studies in different project and company contexts to see if the same phenomena are repeated, or if there are other context specific phenomena not discovered in this study. Quantitative studies would also provide insight in how commonly the reported phenomena repeat in organisations.

This study also provides evidence that there is an interrelationship between the estimation maturity and project management maturity. This is an important observation, and should be confirmed with a quantitative study that considers a large number of projects as well as studied qualitatively to understand the phenomenon. For example, it might just be that companies with a low CMM level do not recognize that there are situations when it is inappropriate to estimate at all (e.g., new development and estimation methods, new product with no client). This is a lack of risk management procedures, not just an estimation problem.

The findings of this paper are based on three projects, and do not provide a generalizable level of confidence for their relationship. The SCE maturity and software process maturity were also assessed only to the extent necessary for the purposes of this study. We suggest that further studies establish a more precise model for assessing SCE maturity and conduct the actual maturity assessment with maturity as the sole focus of the study.

As an exploratory study, the purpose was also to generate new theories and pointers for further research. One interesting observation revealed by this study was that the attitudes towards estimation were negative among the developers participating in estimation, whereas the attitudes of the project managers were positive and the level of commitment to the estimation high. Negative attitudes may be a source of estimation errors, and increase the probability of overruns. This should be studied further, since negative attitudes hinder any work.

From the construct point of view, the aim was to discover organisational factors affecting SCE. We covered many relevant aspects related to the organisational context in which the estimation took place. Thus, we studied what we planned to study and felt that we developed a clear picture of each of the studied projects.

Generally speaking this study found management and process related topics to be equally important from the SCE point of view as esti-

mation technique related topics. This suggests that SCE research would benefit from approaching those topics from a PM or software process point of view, and that elements from these areas should be synthesised into SCE research. Lastly, as demonstrated in the introduction of this paper, e.g. PM research is more advanced than SCE research on management and other organisation related issues.

8. Conclusions

Many researchers and practitioners argue that organisational issues are equally important from the software estimation success point of view as technical issues. Some of the often cited works related to this important topic have been Lederer and Prasad [75], Jørgensen and Shepperd [14] and Magazinovic and Pernstål [10]. Regardless of this knowledge of the importance of organisational issues in SCE, the focus of the SCE research has remained heavily on estimation methodologies and other technical issues.

The findings of this paper have potential to contribute to the current body of knowledge on organisational issues related to SCE, and specifically on top management's role, in several ways, regardless of the limited transferability of the results. By using the exploratory case study approach and interviewing 15 practitioners involved in software development in three organisations, we have found that the role of top management is important in creating prerequisites for meaningful estimation, but their day-to-day participation is not required for successful estimation. Top management may also induce undesired distortion in estimation. We have also found that estimation maturity and estimation success seem to have an interrelationship with software process maturity, but there seem to be no significant individual organisational factors, which alone would make estimation successful. Additionally, our study validated many of the distortions and biases reported in the earlier studies, and showed that the SCE research focus has remained on estimation methodologies.

Low maturity organisations may be able to reduce overruns through a better understanding of their increased risk level and the existence of good estimation practices. We suggest therefore that future studies and software process improvement activities should pay more attention to low maturity organisations and their specific needs.

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Appendix A. Interview instrument

1. Introduction (approximately 5 minutes)
   - A brief introduction to the study.
   - An introduction of the benefits of participation
   - Anonymity and confidentiality.
2. Personal, team and project background (approximately 5 minutes)
   - Interviewee's personal history and job position in the company.
   - Background of the estimated project and the development methodology that was used.
3. Current state of SCE in the organisation (approximately 25 minutes)
   - Describe the procedure for creating the estimate.
   - Describe the method for creating the estimate of the effort required.
   - Describe the responsibilities related to maintaining and improving the software and estimation practices.
   - Describe the outcome of the estimation.
   - Describe the approach to re-estimation during the project.
4. Experiences of organisational phenomena affecting the four SCE aspects (approximately 20 minutes)
   - Describe the management, project manager and personal expectations of the estimate.
   - Describe the overall SCE skills and motivation in your organisation during the estimation.
   - Describe the demonstrated importance and attitudes regarding the estimate.
   - Describe the ways in which top management and other stakeholders were involved in SCE.
   - Did the project have clear goals and realistic expectations?
   - Was there pressure to make the estimate smaller or other pressures?
   - Was the estimate allowed to change over time?
   - Was there enough time allocated for preparing the estimate?
   - Did all stakeholders seek realistic and accurate estimates?
   - What was the level of commitment of different stakeholders to the estimate?
   - What were the primary issues hindering and supporting successful estimation?
5. Ending (approximately 5 minutes)
   - Any other relevant observations that we have not covered?

Appendix B. Software process CMM level assessment summary

The following tables B1, B2, B3 and B4 presents our CMM assessments for levels 2, 3, 4 and 5, respectively, to the case study companies.

Table B1. The key process areas for level 2: repeatable

Process area	Goal	Software Vendor	Service Provider	Tech Giant
Requirements Management	System requirements allocated to software are controlled to establish a baseline for software engineering and management use.	Yes	Yes	Yes
Requirements Management	Software plans, products, and activities are kept consistent with the system requirements allocated to software.	Yes	Yes	Yes
Software Project Planning	Software estimates are documented for use in planning and tracking the software project.	Yes	Yes	Yes
Software Project Planning	Software project activities and commitments are planned and documented.	Yes	Yes	Yes
Software Project Planning	Affected groups and individuals agree to their commitments related to the software project.	N/A	N/A	N/A
Software Project Tracking and Oversight	Actual results and performances are tracked against the software plans.	Yes	Yes	Yes
Software Project Tracking and Oversight	Corrective actions are taken and managed to closure when actual results and performance deviate significantly from the software plans.	Yes	Yes	Yes
Software Project Tracking and Oversight	Changes to software commitments are agreed to by the affected groups and individuals.	N/A	N/A	N/A
Software Subcontract Management	The prime contractor selects qualified software subcontractors.	N/A	N/A	N/A
Software Subcontract Management	The prime contractor and the software subcontractor agree to their commitments to each other.	N/A	N/A	N/A
Software Subcontract Management	The prime contractor and the software subcontractor maintain ongoing communications.	N/A	N/A	N/A
Software Subcontract Management	The prime contractor tracks the software subcontractor's actual results and performance against its commitments.	N/A	N/A	N/A
Software Quality Assurance	Software quality assurance activities are planned.	Yes	Yes	Yes
Software Quality Assurance	Adherence of software products and activities to the applicable standards, procedures, and requirements is verified objectively.	Yes	Yes	Yes
Software Quality Assurance	Affected groups and individuals are informed of software quality assurance activities and results.	Yes	Yes	Yes
Software Quality Assurance	Noncompliance issues that cannot be resolved within the software project are addressed by senior management.	N/A	N/A	N/A
Software Network Management Management	Software configuration management activities are planned.	N/A	N/A	N/A
Software Network Management Management	Selected software work products are identified, controlled, and available.	N/A	N/A	N/A
Software Network Management Management	Changes to identified software work products are controlled.	N/A	N/A	N/A
Software Network Management Management	Affected groups and individuals are informed of the status and content of software baselines.	N/A	N/A	N/A

Notes: Yes – assessment provides evidence of fulfilling the goal; N/A – fulfillment of the goal was not assessed.

Table B2. The key process areas for level 3: defined

Process area	Goal	Software Vendor	Service Provider	Tech Giant
Organization Process Focus	Software process development and improvement activities are coordinated across the organization.	No	Yes	Yes
Organization Process Focus	The strengths and weaknesses of the software processes used are identified relative to a process standard.	N/A	N/A	N/A
Organization Process Focus	Organization-level process development and improvement activities are planned.	No	Yes	Yes
Organization Process Definition	A standard software process for the organization is developed and maintained.	Yes	Yes	Yes
Organization Process Definition	Information related to the use of the organization's standard software process by the software projects is collected, reviewed, and made available.	N/A	N/A	N/A
Training Program	Training activities are planned.	No	Yes	Yes
Training Program	Training for developing the skills and knowledge needed to perform software management and technical roles is provided.	No	Yes	Yes
Training Program	Individuals in the software engineering group and software-related groups receive the training necessary to perform their roles.	No	Yes	Yes
Integrated Software Management	The project's defined software process is a tailored version of the organization's standard software process.	N/A	N/A	N/A
Integrated Software Management	The project is planned and managed according to the project's defined software process.	Yes	Yes	Yes
Software Product Engineering	The software engineering tasks are defined, integrated, and consistently performed to produce the software.	Yes	Yes	Yes
Software Product Engineering	Software work products are kept consistent with each other.	N/A	N/A	N/A
Intergroup Coordination	The customer's requirements are agreed to by all affected groups.	No	Yes	Yes
Intergroup Coordination	The commitments between the engineering groups are agreed to by the affected groups.	N/A	N/A	N/A
Intergroup Coordination	The engineering groups identify, track, and resolve intergroup issues.	N/A	N/A	N/A
Peer Reviews	Peer review activities are planned.	No	Yes	Yes
Peer Reviews	Defects in the software work products are identified and removed.	Yes	Yes	Yes

Notes: Yes – assessment provides evidence of fulfilling the goal; No – assessment provides evidence of not fulfilling the goal; N/A – fulfillment of the goal was not assessed.

Table B3. The key process areas for level 4: managed

Process area	Goal	Software Vendor	Service Provider	Tech Giant
Quantitative Process Management	The quantitative process management activities are planned.	No	Yes	Yes
Quantitative Process Management	The process performance of the project's defined software process is controlled quantitatively.	N/A	N/A	N/A
Quantitative Process Management	The process capability of the organization's standard software process is known in quantitative terms.	No	Yes	Yes
Software Quality Management	The project's software quality management activities are planned.	Yes	Yes	Yes
Software Quality Management	Measurable goals for software product quality and their priorities are defined.	N/A	N/A	N/A
Software Quality Management	Actual progress toward achieving the quality goals for the software products is quantified and managed.	N/A	N/A	N/A

Notes: Yes – assessment provides evidence of fulfilling the goal; No – assessment provides evidence of not fulfilling the goal; N/A – fulfillment of the goal was not assessed.

Table B4. The key process areas for level 5: optimizing

Process area	Goal	Software Vendor	Service Provider	Tech Giant
Defect Prevention	Defect prevention activities are planned.	Yes	Yes	Yes
Defect Prevention	Common causes of defects are sought out and identified.	N/A	N/A	Yes
Defect Prevention	Common causes of defects are prioritized and systematically eliminated.	N/A	N/A	N/A
Technology Change Management	Incorporation of technology changes are planned.	N/A	N/A	N/A
Technology Change Management	New technologies are evaluated to determine their effect on quality and productivity.	N/A	N/A	N/A
Technology Change Management	Appropriate new technologies are transferred into normal practice across the organization.	N/A	N/A	N/A
Process Change Management	Continuous process improvement is planned.	No	Yes	Yes
Process Change Management	Participation in the organization's software process improvement activities is organization wide.	No	Yes	Yes
Process Change Management	The organization's standard software process and the projects' defined software processes are improved continuously.	No	Yes	Yes

Notes: Yes – assessment provides evidence of fulfilling the goal; No – assessment provides evidence of not fulfilling the goal; N/A – fulfillment of the goal was not assessed.