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SOURCES OF UNCERTAINTY IN INFORMATION SYSTEM DEVELOPMENT PROJECTS

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ABSTRACT

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Information system development (ISD) projects are characterized by complexity, intangibility, and high likelihood for changes – all of which heighten the role of uncertainty. Prior IS/IT research has researched uncertainty mainly from specific perspectives, such as software project management, but it is essential to understand the problem widely as well. Uncertainty can be felt due to various sources. Being able to identify and prioritize uncertainty sources is a fundamental aspect of uncertainty management. However, majority of IS/IT research has utilized lists of uncertainties created based on expert intuition rather than empirical research. There is also a lack of continuity in the research regarding sources of uncertainty. It's rare that two studies utilize the same taxonomy rather than creating one customized for their needs. This study adopted an earlier empirically devised taxonomy of sources of uncertainties to further validate it and complement it with the perceived frequency of uncertainty due to each source. Additionally, differences in uncertainty perception between inexperienced and experienced ISD professionals were analyzed. The results from the survey of 64 ISD professionals extend and complement current knowledge on sources of uncertainty and uncertainty perception among professionals with different levels of experience. Additionally, the study discussed both academic and practical implications of these findings to both, as well as future research opportunities.

Keywords: uncertainty, sources of uncertainty, information system development, uncertainty management

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Tietojärjestelmäkehityshankkeille on ominaista monimutkaisuus, aineettomuus ja muutosten suuri todennäköisyys, jotka kaikki lisäävät epävarmuuden merkitystä niissä. Aikaisemmassa tietojärjestelmätieteen tutkimuksessa epävarmuutta on tutkittu lähinnä tietyistä näkökulmista, kuten ohjelmistoprojektien hallinta, mutta on tärkeää ymmärtää ongelmaa myös laajemmin. Epävarmuuden takana voi olla useita erilaisia lähteitä. Kyky tunnistaa ja priorisoida epävarmuuden lähteitä on epävarmuuden hallinnan perustavanlaatuinen näkökohta. Suurimmassa osassa epävarmuutta käsittelevässä tietojärjestelmätieteen tutkimuksessa on kuitenkin hyödynnetty epävarmuusluetteloita, jotka on luotu pikemminkin asiantuntijoiden intuition kuin empiirisen tutkimuksen perusteella. Epävarmuuden lähteitä koskevassa tutkimuksessa ei myöskään ole juurikaan jatkuvuutta. On harvinaista, että kahdessa tutkimuksessa hyödynnetään samaa taksonomiaa sen sijaan, että luotaisiin omiin tarpeisiin räätälöity versio. Tässä tutkimuksessa omaksuttiin aiempi empiirisesti laadittu epävarmuuden lähteiden taksonomia. Tutkimus validoi sitä alkuperäistä isommalla otannalla ja täydensi sitä kustakin lähteestä johtuvan epävarmuuden esiintymistiheydellä. Lisäksi analysoitiin noviisien ja kokeneiden tietojärjestelmäkehityksen ammattilaisten välisiä eroja tiettyjen epävarmuuden lähteiden esiintymistiheydessä. Kyselytutkimuksen tulokset laajentavat ja täydentävät nykyistä tietämystä yleisistä epävarmuuden lähteistä ja epävarmuuden esiintymistiheyden eroista eri kokemustasojen ammattilaisten keskuudessa. Lisäksi tutkimuksessa käsiteltiin näiden löydösten merkitystä akateemiselle tutkimukselle ja ammatinharjoittajille sekä tulevaisuuden tutkimusmahdollisuuksia

Asiasanat: epävarmuus, epävarmuuden lähteet, järjestelmäkehitys, epävarmuuden hallinta

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1 INTRODUCTION

Information system development (ISD) projects are complex, intangible and prone to changes (Jun et al., 2011). While uncertainty is present in all projects, these characteristics inflate its role in ISD. It is no surprise then that less than third of software projects are deemed successful in terms of being valuable, on goal, and satisfactory (The Standish Group, 2015). Uncertainty has been studied extensively in project management research and from the project manager's perspective (Atkinson et al., 2006; Little, 2005; MacCormack & Verganti, 2003; Ward & Chapman, 2003). In the field of IS research, uncertainty is often studied from a specific perspective (Ibrahim et al., 2009; Taipalus et al., 2020). Such perspectives can relate to employee role, such as software developer (Dönmez & Grote, 2018), business domain, such as supply chain management (Simangunsong et al., 2012), development activity such as design (Ball et al., 2010), system attribute, such as reliability (Ibrahim et al., 2009), or operational area, such as outsourcing (Jun et al., 2011). However, generalizability of results and understanding a phenomenon widely are also valid goals for IS research (Lee, 1989; Siponen & Klaavuniemi, 2019). Another issue with uncertainty discussion in the IS field, identified by Taipalus et al. (2020), is that the sources of uncertainty are often not based on scientific evidence, but on educated speculation.

This research builds on the exploratory study by Taipalus et al. (2020), in which they interviewed a diverse group of ISD professionals to empirically devise a taxonomy of causes and effects of uncertainty in ISD projects as well as mechanisms to cope with their effects. In this study, we empirically explore (RQ1) which of the sources of uncertainty are most often behind the uncertainty felt by ISD professionals. The results further validate the taxonomy created by Taipalus et al. (2020) with a larger sample size and complement it with information regarding the frequency of each source. This will allow for future, more detailed studies to focus on the most frequent sources of uncertainty or other related attributes, such as the business impact of the different sources. A better understanding of the most frequent sources of uncertainty can also help ISD practitioners to cope with or mitigate negative outcomes as well as seize the positive outcomes. Additionally, we want to explore whether and how do the results differ based on ISD work experience (RQ2), which might have implications on, for example, project management or employee introduction practices in ISD projects.

- RQ1: Due to which sources is uncertainty most frequently felt by ISD professionals in ISD projects?
- RQ2: How does the frequency of uncertainty felt due to specific sources differ between experienced ISD professionals and their less experienced counterparts?

This paper continues with the definition of key concepts, such as uncertainty and information system development, and synthetization of previous business, project management, IT, and IS research on uncertainty, its significance, and its sources. We then present the research setting for this study, consisting of empirical data collection and analysis. The results from the data analysis are divided into two sub-chapters that each answer a research question. We conclude with discussion on the research's implications for both research and industry, its limitations and threats to its validity, as well as suggestions for future research.

2 RELATED WORK

This chapter presents and synthesizes prior literature related to uncertainty in IS research and related fields. We start by discussing the various definitions of uncertainty and its effects on individuals, organizations, and projects. We continue with the definition of information system development (ISD) and the special characteristics of uncertainty in this context. Following, we define uncertainty management and present two prevalent frameworks to manage uncertainties in IS projects. The chapter ends with discussion and synthesis of prior research on the core topic of this paper, sources of uncertainty.

2.1 Defining uncertainty

There are far fewer things that can be said to be certain than can be said to be uncertain. It is then only natural that uncertainty has been studied in numerous fields and from various perspectives. Economists are interested in how uncertainty about income affects consumption (Castelnuovo et al., 2017), psychologists want to know how we make decisions under uncertainty (Tversky & Kahneman, 1974), and mathematicians want to measure it (Klir & Smith, 2001). To stay relevant to the topic at hand, this chapter only uses research from the fields of business, project management, information technology, and information systems science to discuss the definition of uncertainty and its significance.

Researchers cannot agree on a definition for uncertainty, but they do agree that there are various (Dönmez & Grote, 2018; Jalonen, 2011; Lipshitz & Strauss, 1997; MacCormack & Verganti, 2003). Uncertainty can be studied from the plain English perspective of variability due to 'lack of certainty' on performance measures, such as cost or duration (Ward & Chapman, 2003). It can also be conceptualized as the human feeling of not being sure that one has complete, consistent, and accurate information to make a decision or complete a task (Ibrahim et al., 2009). Similarly, Taipalus et al. (2018) define uncertainty as the emotion caused by certain, subjective levels of ambiguity. For others, the concept centers around information (Dönmez & Grote, 2018). It arises from incomplete, ambiguous, and equivocal information (Jalonen, 2011). Whether approached as an emotion or difficulty to complete a task, we can agree that it is about not knowing something for sure. This paper follows the definition of Taipalus et al. (2018) that uncertainty is an emotion caused by certain, subjective levels of ambiguity.

When defining uncertainty, one often comes across the concept of risk. Uncertainty and risk have been used interchangeably in the past, but the more recent research often makes a gap between them (Dönmez & Grote, 2018; Ward & Chapman, 2003). Traditionally risks have only negative outcomes, while most agree that uncertainties can have both negative and positive outcomes. Following this distinction, many risks and uncertainties arise from the same underlying concepts (Barki et al., 1993). To illustrate, let's consider a risk factor, "team turnover", and an uncertainty factor, "personnel changes" that are similar in nature. With the risk factor, a person leaving is always considered a negative. In contrast, what if that person was a true liability to the company and getting rid of him was a blessing in disguise? Additionally, the uncertainty factor includes the positive uncertainty of e.g., successfully recruiting new employees to tough-to-fill vacancies. Another often cited difference was put forward by Knight (1921): risks refer to events that lead to an outcome that can be assigned a probability, while uncertainties are "unknown-unknowns" and refer to something that is immeasurable (Dönmez & Grote, 2018). Compared to uncertainty, risk management is an extensively researched topic, especially in the field of project management. For example, Wallace & Keil (2004) analyzed the relative importance of 53 software project risk factors, identified in a chain of previous research, with a survey of 507 software project managers.

2.2 The effects of uncertainty

Uncertainty is such a fundamental part of our world and the human experience that it affects each individual and every organization. Effects of uncertainty can be viewed from the perspective of individuals, organizations, or projects. It can even be argued that uncertainty is a requirement for profit: if everything followed universally known and immutable laws the value from any endeavour would be perfectly divided between the participating actors (Knight, 1921). For individuals, uncertainty can be a source of, for example, dissatisfaction or unnecessary work. Remembering the dual nature of uncertainty, it can also be a source of positive effects. For example, self-improvement: not knowing everything is a pre-requisite for learning something new (Taipalus et al., 2020). For organizations, we can go back to the previous example of personnel changes. A company might be able to recruit a software genius, or they might lose one to a competitor. The results from Jun et al. (2011) study show that higher inherent uncertainty in ISD projects has a direct negative effect on both process and product performance. Additionally, software development projects where the project management approach fits the demands set by the level of uncertainty in the project environment will be more successful than projects where it does not (Barki et al., 2001).

2.3 Uncertainty in information system development

Uncertainty has a particularly large role in information system development because the projects are complex, intangible, and prone to changes (Jun et al., 2011). Information systems are socio-technical systems that consist of humans, hardware, software, and data. While there are visible milestones for hardware parts of the system, the progress with software and data is intangible. As a project manager for a housing development, one can visit the site and visually assess the situation, but with complex software systems similar review is impossible. Partly due to this intangibility, ISD projects commonly experience changes to original requirements as new feature requests arise during development. Clients might not have a clear vision for the system to be developed to begin with and they may view software as easier to change than physical systems (Jurison, 1999). In the IT field, software development and information system development are sometimes used interchangeably. We adopt the view from Taipalus et al. (2020) that software development is a subset of ISD that focuses on the technical development of an information system. This definition of ISD also contains the contextual aspects such as the management of an ISD project. Perhaps partly due to the vastness of the concept, most IS research on uncertainty has focused on a specific perspective (Dönmez & Grote, 2018; Jun et al., 2011; Taipalus et al., 2020).

In a single ISD project there are often professionals from numerous different fields involved: software development, project management, UI design, UX design, business analysis, and networking - to name a few. Many researchers have chosen to focus on uncertainty experienced by one role, such as managers or software developers (Jun et al., 2011; Jurison, 1999; Ubayashi et al., 2019). This allows them to use lower level of abstraction and study constructs that are specific to that role. For example, Ubayashi et al. (2019) use commit messages from a popular version control system Git to evaluate when and why software developers experience uncertainty.

In a similar strain, many studies approach uncertainty from the perspective of a specific development activity, such as design or implementation. For example, Ball et al. (2010) studied the role of uncertainty in mediating between complex requirements and depth-first design in software design and Saarinen & Vepsäläinen (1993) studied how to find the right combination of experimental and rational approaches for implementation in projects with differing levels of complexity and uncertainty. Letier et al. (2014) suggest that uncertainty is most prevalent in the early stages of development, when organizations make strategic decisions on information system investments and IT architects decide on overall organization of the system to be developed. The large amount of research on uncertainty in the early stages of ISD, such as requirements uncertainty, supports their view. As an extreme, an often referenced study by Alter & Ginzberg (1978) used eight risk factors which all relate to the early stages of the project, before writing a single line of code.

Uncertainty research from the perspective of a specific business domain, such as supply chain management, offers important insights into the interplay of uncertainty, information systems, and domain-specific elements. However, the domain specific lens also leads to emphasis on factors that are in the core of that domain. In their review of supply chain uncertainty, Simangunsong et al. (Simangunsong et al., 2012) identified 14 sources of uncertainty from prior models. While there are several factors that apply to ISD in general, such as environment, there are also several factors specific to supply chain management, such as order forecast horizon. In addition to the already mentioned perspectives, uncertainty has been commonly researched from the viewpoint of a specific operational area, such as outsourcing, and system attributes, such as reliability.

Despite a large body of IS research on uncertainty, it can be argued that uncertainty in ISD is not widely understood because the research has focused on these specific perspectives (Taipalus et al., 2020). There is a lack of understanding on the common sources, effects and management approaches of uncertainty that apply to all ISD. In addition, approaching uncertainty from a role-agnostic perspective may give a more balanced view of how uncertainty affects ISD projects as a whole. Each role might be prone to emphasize the uncertainties close to their own role.

2.4 Uncertainty management

Managing uncertainties is central to successful ISD projects as demonstrated in the chapter on effects of uncertainty. Common project management practice does not consider the range of uncertainty sources in projects (Atkinson et al., 2006). More sophisticated efforts are required to recognize and manage important sources of uncertainty. The two main approaches for managing uncertainty are coping and minimization (Dönmez & Grote, 2018; Simangunsong et al., 2012). Minimization strategies aim to eliminate as much of the uncertainty as possible, while coping strategies try to add flexibility to projects to better address the uncertainties. For example, the Stage-Gate model of managing software projects introduces rigorous planning and monitoring processes to minimize uncertainty upfront (Bianchi et al., 2020). While minimization might sound an obvious candidate, it is not an all-encompassing solution. In many situations the sources of uncertainty might be outside the uncertainty manager's influence, such as personnel changes in a client organization. At the same time, eliminating uncertainty does not only eliminate negative outcomes, but also the positive ones. Significant portion of the uncertainty literature has focused solely on reduction of uncertainty, ignoring the positive aspects (Kolltveit et al., 2004). A company that eliminates all uncertainty by utilizing only tried-and-tested solutions and processes does not innovate. Coping with uncertainties is a more subtle approach where understanding the source of uncertainty is in a key role. For example, results from Taipalus et al. (2020) suggest that close involvement with the client is crucial in preventing unnecessary work caused by uncertainty. In a more general view, the popularity of agile project management methods can be seen as an attempt to cope with uncertainty through increasing flexibility instead of minimising uncertainty. In a similar vein, the Stage-Gate model has seen an evolution towards coping with the introduction of *flexible* Stage-Gate (Biazzo & Filippini, 2021). Ibrahim et al. (2009) state that prior proposed solutions to managing uncertainty in software development context have focused on specific development activities, such as testing, or specific system attributes, such as reliability. Below we present their attempt at creating a more comprehensive framework for uncertainty management and a newer, competing approach from Marinho et al. (2018).

Ibrahim et al.'s (2009) attempt at a comprehensive uncertainty management framework divides uncertainty management into four consecutive steps: (1) identification and prioritization, (2) modelling and analysis, (3) management and planning, and (4) monitoring and evaluation (Figure 1). In the first phase, various sources and types of uncertainty, such as requirements uncertainty, are identified. These identified sources are then ranked based on estimated severity. In the second phase, the selected uncertainty sources are modelled with an uncertainty modelling technique, such as fuzzy logic (Celikyilmaz & Turksen, 2009). The modelled uncertainty is then analyzed to estimate its possible effects with or without proper management. In the third phase, plans for managing the uncertainties are created. The plans should propose actions for managing and mitigating the consequences of uncertainty. The authors note that these plans should allow for flexibility, as it's often costly and inefficient to try to eliminate all uncertainty. In the fourth and final phase, the uncertainty management plans are evaluated in action for their effectiveness and monitored for possible changes. Here the authors highlight the need to document decisions and their rationale during management to allow for better reuse of knowledge and previous experiences in the future.

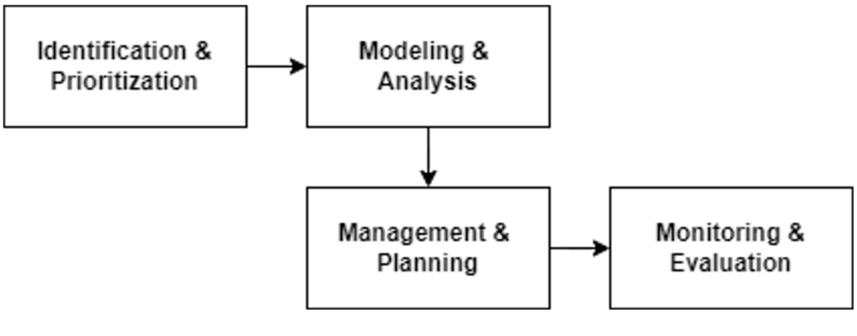

FIGURE 1 Uncertainty management framework phases (Ibrahim et al., 2009, p.8)

Marinho et al. (2018) approach to managing uncertainty starts with characterizing the project: identifying the project type, analysing stakeholders, and defining success criteria (Figure 2). This characterization can be utilized to adopt a proper management approach, such as agile or waterfall, and to identify uncertainties in project goals and stakeholder interests. Next up is identifying sources of uncertainty. Here Marinho et al. (2018) recommend using a frame of four high-level uncertainties to guide the process: technological uncertainty, market uncertainty, environmental uncertainty, and socio-human uncertainty. Project managers should use these uncertainties as lenses and utilize learnings from past projects, cause and effect diagrams, scenario building, and knowledge mapping to identify specific uncertainties for the project. Detecting early signs of uncertainty is concerned with issues such as team mood, contradictions in reporting, or late deliveries by suppliers. According to the authors, managers can improve their ability to detect early warning signs of uncertainty in a project through mindfulness. Mindfulness can be established through five attributes: attending to concerns regarding failure, reluctance to simplify interpretations, operations sensitivity, commitment to resilience, and skill considerations. Additionally, managers can use the list of main early warning sign groups, such as “gut feelings” and “communication”, as a guide during the project cycle. The identification of early warning signs is accompanied with sensemaking. Sensemaking is a process to analyze signals and build meaning around them. It consists of interpreting and translating the signal to an objective form, revealing one’s own assumptions and beliefs, and finally building a shared meaning.

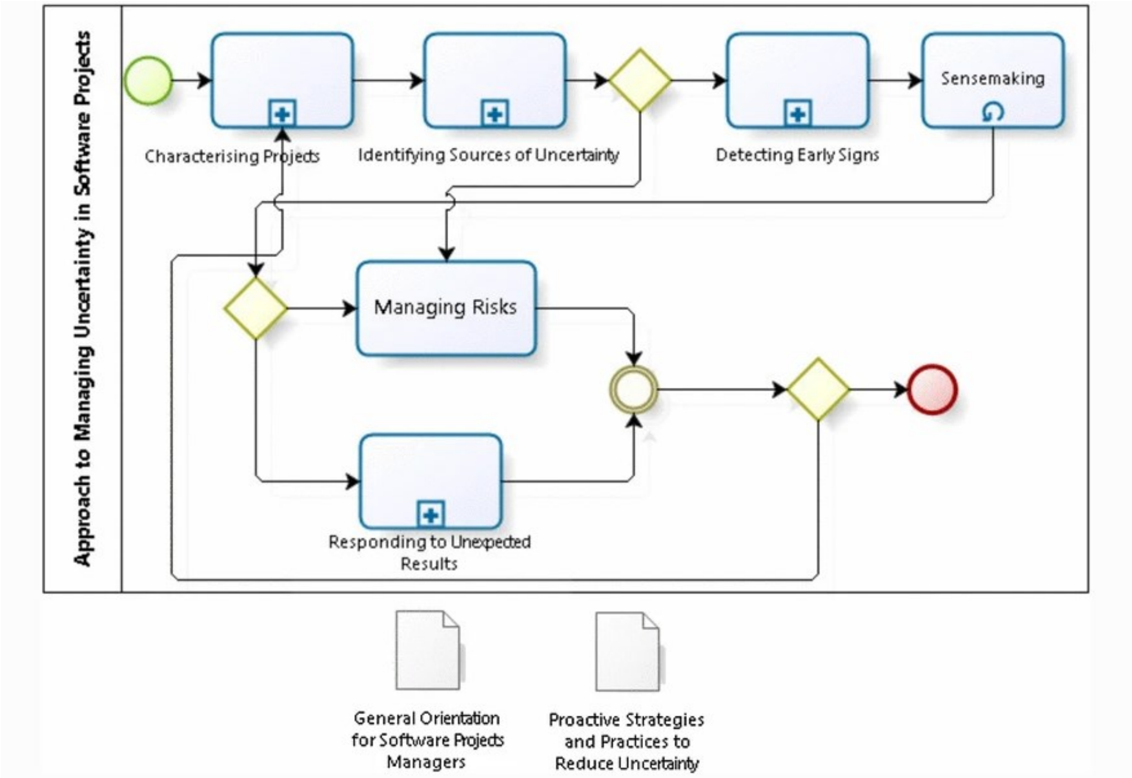

FIGURE 2 Approach to managing uncertainty in software projects (Marinho et al., 2018, p.166)

Both sets of authors base their approaches on the negative view of uncertainty criticized by, for example, Dönmez & Grote (2018). The management is focused on coping and minimization, while all but ignoring the possible positive outcomes of uncertainty. Ibrahim et al.'s (2009) model includes both qualitative and quantitative (modeling) analysis of the uncertainty, while Marinho et al.'s (2019) discusses only qualitative methods. The process of uncertainty management is similar in both frameworks, but Marinho et al. (2018) offer the reader more detailed tools to implement their approach. The authors agree that identifying and considering diverse forms of uncertainty is central to uncertainty management. While Ibrahim et al. (2009) are content with just providing examples on sources of uncertainty, Marinho et al. suggest concrete ways to identify different sources of uncertainty affecting a particular project, such as creating knowledge maps. When undertaking such a task, a list of common uncertainty sources in ISD, based on empirical data, can act as a foundation for a more customized product.

2.5 Sources of uncertainty

A common approach in literature is to treat uncertainty as a singleton (e.g., Khatun et al., 2022), or to focus on a specific type of uncertainty, such as requirements uncertainty (Dönmez & Grote, 2018). However, as highlighted in the uncertainty management frameworks presented in the previous chapter and prior IS literature on uncertainty, identifying distinct sources of uncertainty is essential to successfully managing them. Different uncertainty sources may have different effects on a project and may require different management approaches. Lists of uncertainty sources used in IS literature range from comprehensive taxonomies with tens of distinct factors (e.g. Barki et al., 1993) to just separating internal and external uncertainty (e.g. Kolltveit et al., 2004). The categorizations differ greatly from study to study even within the IS research field. Each author adapts a taxonomy and abstraction level fitting to their study's specific needs. The chosen sources of uncertainties are often based on educated speculation instead of empirical research. Below we briefly discuss some categorizations of uncertainty sources from project management, business and IS research. These categorizations are summarized in Table 1.

The sources of uncertainty have been studied in both general project management and IS contexts. Atkinson et al. (2006) present the fundamental uncertainties in general project management setting. They categorize them in three key areas: uncertainty associated with estimating, uncertainty associated with project parties, and uncertainty associated with stages of the project life cycle. Each of these categories holds several uncertainty factors, such as "the objectives and motivation of each party" under "Uncertainty associated with project parties". While their list of uncertainties is comprehensive for project management, it does not consider the unique characteristics of ISD nor is it based on empirical data. Within IS research, there are multiple studies that research uncertainty in software development. Little (2005) recognizes four uncertainty attributes: market uncertainty, technical uncertainty, project duration, and project dependencies. Interestingly, while many studies include complexity as a factor increasing uncertainty, Little (2005) separates complexity and its attributes from uncertainty. Dönmez & Grote (2018) adopt a classification of uncertainty in software development through reviewing previous literature and interviewing software developers. In their classification uncertainties are divided into requirement uncertainty, resource uncertainty, and task uncertainty. Jun et al. (2011) separate between uncertainty inherent in the project and risks that emerge during the project, because according to Alter and Sherer (1978), the factors that exist prior to a particular project or project phase may need to be managed differently to those that emerge during that project or phase. Their taxonomy of uncertainty factors inherent in projects consist of relative project size, technical complexity, development team skill, and client/user experience.

TABLE 1 Uncertainty sources in previous literature

Study	Scope	Perspective	Sources based on empirical data	Presented classification
Little, 2005	Software development	Project manager	No	Market uncertainty, technical uncertainty, project duration, dependencies
MacCormack & Verganti, 2003	Software development	Project manager	No	Platform uncertainty, market uncertainty
Dönmez & Grote, 2018	Software development	Software developer	No	Requirement uncertainty, resource uncertainty, task uncertainty
Moynihan, 2000	Information System Development	Requirements uncertainty, project manager	Yes	Hidden agenda, internal disagreement, major change to customer's workflow/procedures, new application, having to balance between differing needs of multiple groups of users, creating an adaptable enough system that can cope with unknown future needs, complex application logic, dealing with inexperienced computer users
Jun et al., 2011	Information System Development	Vendor, project manager	No	Relative project size, technical complexity, development team skill, client/user experience
Barki et al., 1993	Software development	Risk management	No	Size, technological complexity, technological change, technological newness, novelty of application, extensive-specific learning required, time pressure, task structure, personnel changes, analyst training and experience, analyst experience, task proficiency, general level of training, number of users, type of users, user support, users' feelings of responsibility, lack of upper management support
Ziv & Richardson, 1996	Software development	Software testing	No	Human participation, concurrency, and problem-domain uncertainties
Saarinen & Vepsäläinen, 1993	Software development	Implementation	No	Information system characteristics, level of users' abilities before implementation, level of system analysts' abilities before implementation, familiarity with the methodology
Alter & Ginzberg, 1978	Management Information Systems	Implementation	No	Designer lacking prior experience with similar systems, nonexistent or unwilling user, multiple users or designers, turnover among users, designers, or maintainers, lack of support for system, inability to specify purpose or usage patterns in advance, inability to predict and cushion impact on all parties, technical problems, cost-effectiveness issues
Marinho et al., 2018	Software development	Uncertainty management	No	Technological uncertainty, market uncertainty, environmental uncertainty, socio-human uncertainty
Haleem et al., 2021	Software development	Requirements uncertainty	No	Project uncertainty, organizational uncertainty, relational uncertainty, environmental uncertainty, market uncertainty, socio-human uncertainty, resource uncertainty
Taipalus et al., 2020	Information System Development	Vendor side in ISD projects	Yes	Personal matters, inefficient conventions, organizational pathoses, lack of interdisciplinary knowledge, lack of problem understanding, conflicts of interest, technical considerations, causes outside the scope of influence

There is significant overlap in the contents of the categorizations, but at the same time it is rare for studies to use the same set of uncertainty sources. Varying perspectives, abstraction levels, and terminology make it difficult to compare the categorizations. Most studies have a source related to the technical side of the information system, such as technological uncertainty or technological complexity. Some studies exclude uncertainty sources outside the participating organizations (Alter & Ginzberg, 1978; Barki et al., 1993), while others include them under market uncertainty (Little, 2005; Marinho et al., 2018). Majority of the studies include some human aspects, but again the extent varies. For example, Jun et al. (2011) do not discuss interpersonal issues, while Haleem et al. (2021) and Taipalus et al. (2020) feature them prominently. This review also supports the notion by Taipalus et al. (2020) that majority of IS research uses uncertainty sources that are not based on empirical research. In studies where the sources of uncertainty are not central to the research, a simplified categorization with a handful of sources with high-level abstraction is often used.

This study adopts the taxonomy of the sources of uncertainty in ISD from Taipalus et al. (2020), who devised it based on eleven semi-structured interviews with ISD professionals and through conventional content analysis (Table 2). While in the original study the taxonomy refers to causes of uncertainty, a more neutral term, source, was adopted for this study. The term source is widely used in prior IS research and has fewer negative connotations than cause, making it a better fit for the perspective that uncertainty is not inherently negative or positive. The taxonomy is organised to three levels with different level of abstractions.

TABLE 2 Causes of uncertainty from Taipalus et al. (2020, p.5)

Causes of uncertainty	Causes stemming from within the development organization	Personal matters	Lack of trust Fear Personal problems outside work
		Inefficient conventions	Large team size Lack of knowledge concerning roles Unsuitable communication channels Different personal working methods Agile methods Incompetence
		Organizational pathoses	Inconsistent resource allocation Organizational complexities Failure handling
	Causes stemming from the client organization	Lack of interdisciplinary knowledge	Client does not understand software Team does not understand the business domain
		Lack of problem understanding	Lacking initial requirements New features arise Lack of commitment from the client
		Conflicts of interest	Authority–involvement discrepancy Prioritization
	Causes stemming from outside the organizations	Technical considerations	Complex technical environments Technology evaluation
		Causes outside the scope of influence	Changes in surrounding environments Complexities in surrounding environments Lack of suitable workforce

3 RESEARCH SETTING

In the previous chapter we established that understanding uncertainty and its various sources is essential to more successful ISD projects. We highlighted that earlier IS research has focused on specific perspectives and mostly relied on lists of uncertainty sources devised based on expert speculation, not empirical research. To tackle these challenges, we adopt the presented empirically devised taxonomy of uncertainty sources from Taipalus et al. (2020). We seek to further validate it with a larger sample size and complement it with how frequently ISD professional felt uncertainty due to each source (RQ1). As the original taxonomy is based on data collected from professionals working specifically on the vendor side of ISD projects, we also adopt that perspective to better align the two studies. Additionally, we tested whether there were significant differences in the results between experienced ISD professionals and their less experienced counterparts (RQ2). In the sections below, we explain how we collected and analyzed the empirical data used in this study.

3.1 Data collection

The data were collected from professionals working with ISD on the vendor side through a standardized web survey. The survey was distributed through social media (LinkedIn) and professional networks. As this study is interested in the general view of ISD, all the different roles participating in ISD and professionals working in different industries were encouraged to participate. The structure of the survey was organized around the three top-level categories of uncertainty sources from Taipalus et al.'s (2020) study: sources stemming from within the development organization, sources stemming from the client organization, and sources stemming outside the development and client organizations. Each of these top-level categories had its own matrix question where the items were the low-level individual uncertainties of each respective top-level category. As the original taxonomy items were not created to be used in a survey per se, some of the names of the items had to be modified to reduce ambiguity. The modifications include, for example, adding illustrating examples and clarifying the actor in question. The full list of changes is available in Appendix 2. In each of the matrix questions, the respondents were asked to rate how often they had felt uncertainty due to a specific source, e.g., complex technical environments, in their projects during the last three months. The responses were given on a 5-point Likert scale (1 = Never, 2 = Rarely, 3= Sometimes, 4 = Often, 5 = Almost always). The respondents had the option to mark on any question item that they didn’t understand the item or that it isn’t relevant in their ISD context. These responses were then excluded from analysis. To minimize social desirability bias, no information identifying individual respondents, or their workplaces, were asked in the questionnaire. The introduction on the survey landing page included a confidentiality note which assured that the responses would be kept completely confidential and would not be shared with any third parties.

The web survey was opened 416 times and completed 184 times. It is notable that the completion rate of the survey was extremely high: 93% of those who started answering completed the survey. In later verification a significant portion of the completions (100 responses) were identified to be by bots and were eliminated from analysis. Out of the remaining 84 responses, 20 were by professionals who worked on information system development, but not on the vendor side for business customers, and, therefore, were not part of the population for this study. All the remaining 64 answers were deemed valid and used in the subsequent analysis. Figure 3 illustrates the data collection flow from start to finish.

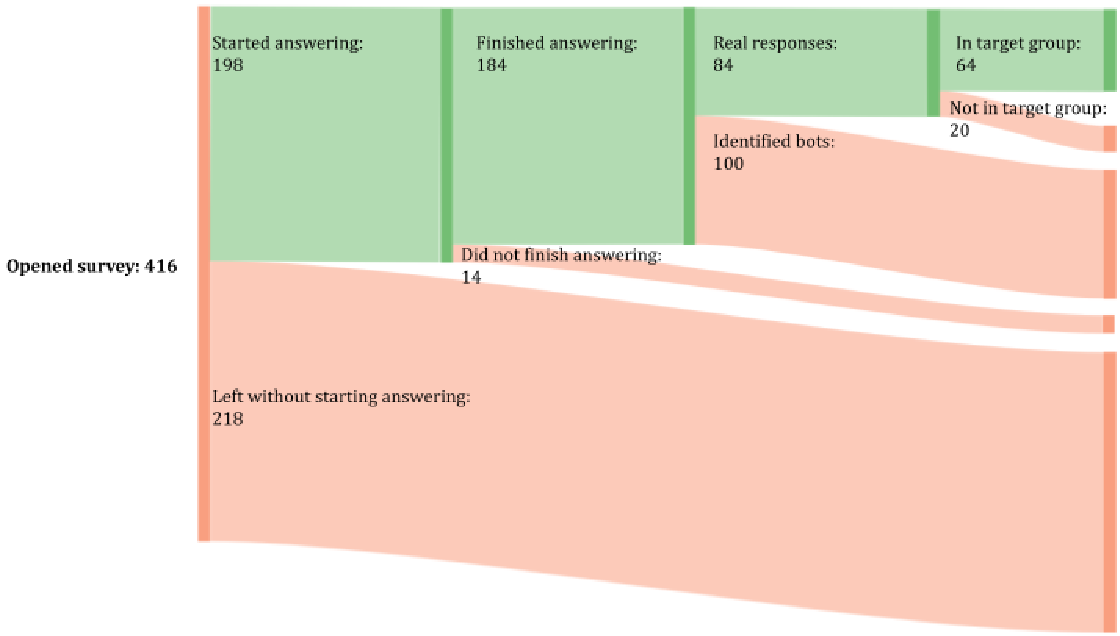

FIGURE 3 Data collection flow

The survey also included demographic questions regarding the respondents' organizations. All the respondents worked in Finland. Figure 4 shows the distribution of the respondents' company sizes based on the number of employees. A clear majority of the respondents work in large companies with more than 250 employees. 78% of the respondents' companies also conduct business internationally. As we had hoped for, the respondents represent a diverse group of ISD professionals of differing seniority levels and 42 unique job titles, ranging from the more technical roles, such as software developer and chief engineer, to the more business-focused roles, such as project manager and product owner.

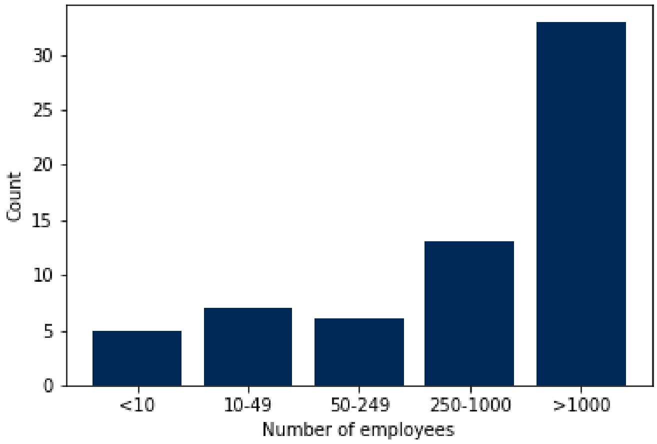

FIGURE 4 Distribution of the respondents' company sizes

3.2 Data analysis

This section presents the statistical methods and tests utilized in answering RQ2. For RQ1, we present descriptive statistics in the Results chapter. To answer RQ2, we divided the respondents into two groups based on their ISD experience: those who reported <=3 years of ISD experience and those with >3 years of ISD experience. While there is no scientific method behind this exact division, our thinking behind this is that after three years a person has familiarized themselves with core components of their role and might experience specific uncertainties differently. We tested for differences in perceived frequency of uncertainty sources in all three levels of the Taipalus et al. (2020) taxonomy, later referenced as top-level, mid-level, and individual sources of uncertainty. The independent samples t-Test is standard for comparing two independent groups, but we chose to utilize the non-parametric Mann-Whitney U test, or Mann-Whitney rank sum test, because of violations of the normality assumption in the data. In the non-parametric Mann-Whitney U test, the variables do not have to conform to any specific distribution curve as the test uses rank sum instead of the mean to check for differences between the groups. Additionally, the method was well-suited for our data due to the following characteristics of the data:

- one ordinal dependent variable
- one independent variable with two categorical independent groups
- independence of observations
- the distribution of answers in both groups of the independent variable had the same shape

In the Mann-Whitney U test, the values are first ranked from smallest to largest. The smallest value in the data is given the rank 1 and the largest value is given the rank *n*. Then the sum of ranks for each group (x, y) is calculated. The Mann-Whitney *U* statistic for each group (U_x, U_y) is calculated based on the sizes of each group and their rank sums with the following formulas:

$$U_x = n_x n_y + ((n_x (n_x+1))/2 - R_x$$
$$U_y = n_x n_y + ((n_y (n_y+1))/2 - R_y$$

where n_x is the number of values in group x and n_y is the number of values in group y, and R_x is the rank sum of group x and R_y is the rank sum of group y. The smaller *U* statistic is the *U* value. Finally, the z-value is calculated from *U*, the expected value of *U*, and standard error of *U*. The z-value can then be transformed to the corresponding p-value to reject the null hypothesis (in the population, the rank sum does not differ in the two groups) or accept the alternative hypothesis (in the population, the rank sum differs in the two groups).

To account for the possibility that our two experience groups (<=3 years and >3 years) had been mis-defined (e.g., differences are significant only after five years of experience), we utilized Spearman's rank-order correlation to assess the relationship between the perceived frequency of uncertainty due to a source of uncertainty and years of ISD work experience. We selected Spearman's correlation because we had two variables, one ordinal and one continuous, that represented paired observations. Like the Mann-Whitney U test, Spearman's correlation uses rank-order and does not assume the data are normally distributed. To analyze the source categories, we created sum variables from the sub-categories under each mid and top-level category. For example, the mid-level uncertainty category "Technical considerations" contained the lower-level categories "Complex technical environments" and "Technology evaluation".

4 RESULTS

In the following sections we present the results from the data analysis in detail. The first section focuses on RQ1, for which the results are presented through descriptive statistics, while the second section concentrates on RQ2 and the results from the statistical tests introduced in the previous chapter. A significance level of $\alpha = .05$ was chosen for all the statistical tests.

4.1 Most frequent sources of uncertainty

The arithmetic means of perceived frequency of uncertainty due to each individual uncertainty source varied from 1.72 for "Fear (e.g. of asking clarifying questions" to 3.39 for "New features arise". The full results are shown in Figure 5.

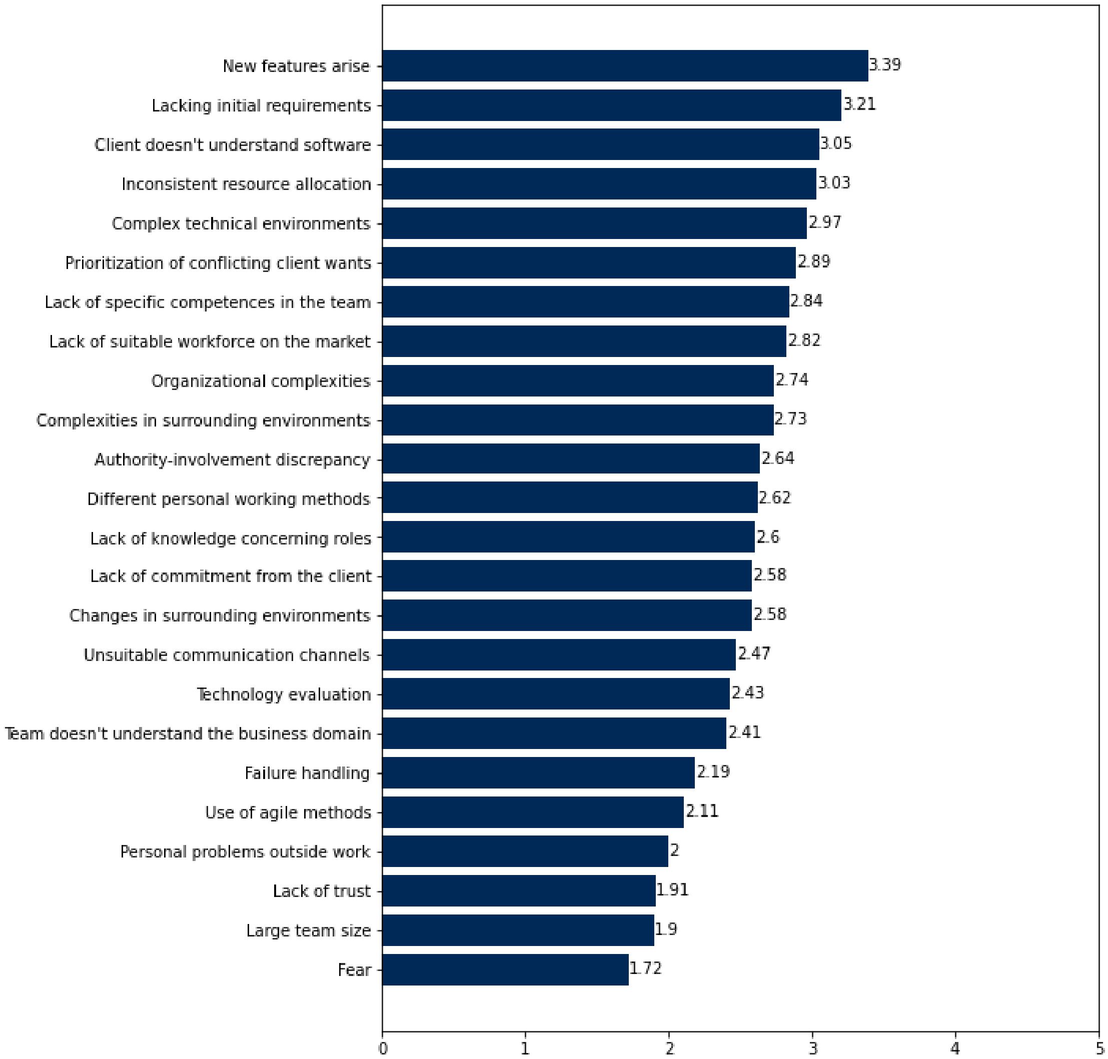

FIGURE 5 Mean perceived frequency of uncertainty from individual uncertainty sources

The arithmetic means for mid-level sum variables varied from 1.88 for "Personal matters" to 3.05 for "Lack of problem understanding. The full results are shown in Figure 6.

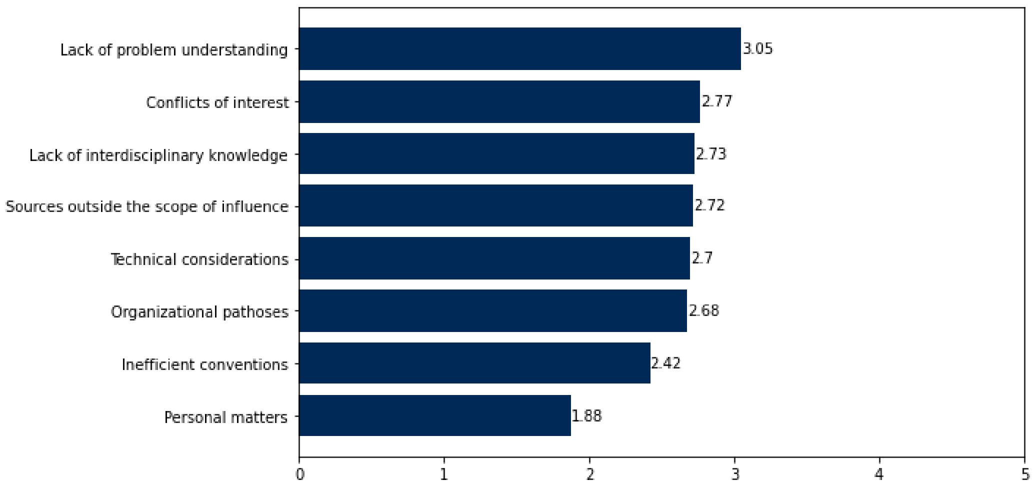

FIGURE 6 Mean perceived frequency of uncertainty from mid-level uncertainty sources

The arithmetic means for top-level sum variables were 2.33 for sources stemming from within the development organization, 2.71 for sources stemming outside the development and client organizations, and 2.85 for sources stemming from the client organization. The full results are visualized in Figure 7.

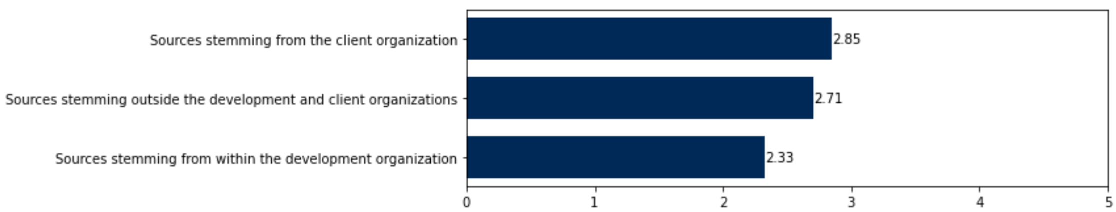

FIGURE 7 Mean perceived frequency of uncertainty from top-level uncertainty sources

4.2 ISD experience and sources of uncertainty

The following sub-chapters present the results from the Mann-Whitney U tests to determine if there were differences in the frequencies of perceived uncertainty between the two experience groups of ISD professionals and from the Spearman's rank-order correlation to assess the relationship between the perceived frequency of uncertainty due to a source of uncertainty and years of ISD work experience.

4.2.1 Differences in individual sources of uncertainty

A Mann-Whitney U test was run to determine if there were differences in the frequencies of perceived uncertainty regarding the 24 sources of uncertainty between the two experience groups of ISD professionals. The full results for each source are shown in Table 3. The *p*-value is **bolded** for sources where there was a statistically significant difference between the groups. Distributions of the scores for the two experience groups were similar, as assessed by visual inspection.

TABLE 3 Mann-Whitney U test for individual sources of uncertainty

	Median				
Source of uncertainty	**<=3 years**	**>3 years**	***U***	***z***	***p***
Lack of trust	1.5	2.0	627.0	1.785	.074
Fear	1.0	2.0	658.0	2.276	**.023**
Personal problems outside work	2.0	2.0	449.0	.092	.926
Large team size	1.5	2.0	501.0	.162	.871
Lack of knowledge concerning roles	3.0	2.0	552.5	1.172	.241
Unsuitable communication channels	2.0	2.0	514.0	.140	.889
Different personal working methods	2.0	3.0	475.5	.400	.689
Use of agile methods	2.0	2.0	501.5	.035	.972
Lack of specific competences in the team	3.0	3.0	552.0	.673	.501
Inconsistent resource allocation	3.0	3.0	545.0	.576	.565
Organizational complexities	3.0	3.0	472.0	.007	.994
Failure handling	2.0	2.0	462.5	.694	.487
Client doesn't understand software	3.0	3.0	467.0	.521	.602
Team doesn't understand business domain	2.0	2.5	491.5	.079	.937
Lacking initial requirements	3.0	3.0	503.5	.250	.803
New features arise	3.5	4.0	445.0	.829	.407
Lack of commitment from the client	3.0	2.0	583.5	1.118	.264
Authority-involvement discrepancy	3.0	2.0	497.5	.091	.928
Prioritization of conflicting client wants	3.0	3.0	549.0	.624	.533
Complex technical environments	3.0	3.0	550.0	.867	.386
Technology evaluation	3.0	2.0	636.5	2.139	**.032**
Changes in surrounding environments	2.0	3.0	436.0	.593	.553
Complexities in surrounding environments	2.0	3.0	358.5	1.062	.288
Lack of suitable workforce on the market	2.5	3.0	371.5	1.252	.211

4.2.2 Differences in mid-level categories of uncertainties

A Mann-Whitney U test was run to determine if there were differences in the frequencies of perceived uncertainty regarding the eight mid-level categories of uncertainty between the two experience groups of ISD professionals. The full results for each source are shown in Table 4. There were no statistically significant differences between the groups regarding the mid-level categories of uncertainty. Distributions of the scores for the two experience groups were similar, as assessed by visual inspection.

TABLE 4 Mann-Whitney U test for mid-level sources of uncertainty

	Median				
Source of uncertainty	**<=3 years**	**>3 years**	***U***	***z***	***p***
Personal matters	2.00	1.67	573.0	1.745	.081
Inefficient conventions	2.67	2.42	488.6	.430	.667
Organizational pathoses	2.33	2.50	447.0	.176	.860
Lack of interdisciplinary knowledge	2.50	2.75	469.0	.239	.811
Lack of problem understanding	3.00	3.33	494.5	.119	.905
Conflicts of interest	3.00	2.50	534.5	.418	.676
Technical considerations	3.00	2.50	627.0	1.931	.053
Causes outside the scope of influence	2.33	3.00	325.0	1.087	.277

4.2.3 Differences in top-level categories of uncertainties

A questionnaire was employed to measure different, underlying constructs. One construct, 'Sources of uncertainty stemming from the development organization', consisted of 12 questions. The scale had a high level of internal consistency, as determined by a Cronbach's alpha of 0.776.

A Mann-Whitney U test was run to

> determine if there were differences in the frequencies of perceived uncertainty stemming from the development organization between the two experience groups. Distributions of the scores for the two experience groups were similar, as assessed by visual inspection. Median scores for <=3 years (2.33) and >3 years (2.17) were not statistically significantly different, $U = 423$, $z = .655$, $p = .512$.
>
> determine if there were differences in the frequencies of perceived uncertainty stemming from the client organization between the two experience groups. Distributions of the scores for the two experience groups were similar, as assessed by visual inspection. Median scores for <=3 years (3.00) and >3 years (3.00) were not statistically significantly different, $U = 465.5$, $z = .036$, $p = .971$.
>
> determine if there were differences in the frequencies of perceived uncertainty stemming from outside the development and client organizations between the two experience groups. Distributions of the scores for the two experience groups were similar, as assessed by visual inspection. Median scores for <=3 years (2.40) and >3 years (2.80) were not statistically significantly different, $U = 387.5$, $z = .057$, $p = .954$.

The results are summarized in Table 5.

TABLE 5 Mann-Whitney U test for top-level sources of uncertainty

	Median					
Sum variable	**<=3 years**	**>3 years**	*a*	*U*	*z*	*p*
Stemming from the development organization	2.33	2.17	.776	423.0	.655	.512
Stemming from the client organization	3.00	3.00	.791	465.5	.036	.971
Stemming outside the development and client organizations	2.40	2.80	.565	387.5	0.57	.954

4.2.4 Correlation between ISD experience and uncertainty

A Spearman's rank-order correlation was run to assess the relationship between perceived frequency of uncertainty due to a source and years of ISD work experience. 64 respondents participated. The correlation was calculated for both top- and mid-level uncertainty categories. There was no statistically significant correlation between any of the top-level categories. The full results are summarized below in Table 6. For the mid-level categories, there was a statistically significant weak negative correlation between perceived frequency of uncertainty due to “Personal matters” and work experience. The full results are summarized below in Table 7.

TABLE 6 Spearman's rank-order correlation for top-level sources of uncertainty

Sum variable	r_s	*p*
Stemming from the development organization	.149	.274
Stemming from the client organization	.046	.720
Stemming outside the development and client organizations	.004	.978

TABLE 7 Spearman's rank-order correlation for mid-level sources of uncertainty

Sum variable	r_s	*p*
Personal matters	-.270	**.035**
Inefficient conventions	-.082	.530
Organizational pathoses	.002	.988
Lack of interdisciplinary knowledge	.007	.957
Lack of problem understanding	-.067	.603
Conflicts of interest	-.071	.580
Technical considerations	-.210	.099
Causes outside the scope of influence	.093	.489

5 DISCUSSION

In this chapter we connect the results from the empirical study to the theoretical background and discuss their implications for both academic research and industry practice.

5.1 Implications for research

A key deficiency in earlier IS uncertainty research has been the lack of empirically devised sources of uncertainty. This study further validated the taxonomy proposed by Taipalus et al. (2020) with a larger sample size. The presented uncertainty sources were found relevant by ISD professionals as only 1.63% of the responses were "not understood/irrelevant". This study is the first empirical research into the frequency of uncertainty from different sources in ISD context and the differences in uncertainty perception due to the amount of ISD work experience. ISD professionals most frequently felt uncertainty due to new features arising during development and lacking initial requirements. The results are in line with prior research and expert intuition, as both issues have been extensively discussed. Additionally, prioritization of conflicting client wants has been highlighted in previous uncertainty and risk research in various forms. Notably, in a previous study on requirements uncertainty by Moynihan (2000), the two constructs most likely to have a very big difference on project success were both related to prioritization of conflicting client wants: *the real agenda of the client seems to be hidden* and *the clients disagree amongst themselves about what's needed*. These results combined with our new findings suggest that prioritization of conflicting client wants is both a frequent and high impact source of uncertainty and should be prioritized in uncertainty management.

Lack of suitable workforce on the market was a frequent source of uncertainty amongst the respondents. Even though, based on a subjective assessment of the job titles, majority of them were not in a managerial position or directly responsible for hiring talent. This suggest that the much debated shortage of IT talent (e.g., Kainulainen, 2021) has indirect effects on uncertainty felt by other employees as well. This could be connected to the fourth-most frequent source, inconsistent resource allocation, as well as lack of specific competences in the team. Inconsistent resource allocation is also the highest-ranking uncertainty source internal to the development organization. While companies compete for talent, existing employees might need to occasionally stretch to cover for those changing workplaces and when recruiting does not go as expected. Such speculations are supported by a recent study by Hyrynsalmi et al. (2018), who questioned top managers from Finnish software companies regarding the labor shortage. They found out that the war for talent in software business leads to projects not being taken, working overtime, and increases in development time.

Several researchers have studied the problem of identifying the best communication channels for ISD (e.g., Mishra & Mishra, 2009; Pikkarainen et al., 2008). Our results suggest that ill-suited communication channels are indeed responsible for some uncertainty, but they are not as frequent of a source as some of the already mentioned ones. Ahmad et al. (2018) studied the benefits of various communication channels in agile software development. For example, face-to-face is seen as the preferred communication channel for collecting requirements. The coronavirus pandemic greatly reduced the amount of face-to-face communication during the data collection period and the 3-month look-back window on projects. If we infer that the preference for face-to-face communication for collecting requirements would mean that it is also the most effective one, the lack of that possibility could have influenced the high frequency of uncertainty from both lacking initial requirements and additional features during development.

The results reinforce the notion that ISD is a complex undertaking (e.g., Jun et al., 2011). All three complexity related sources – complex technical environments, organizational complexities, and complexities in surrounding environments – were in the upper half of the 24 uncertainty sources, in that order. The frequency of uncertainty from complex technical environments suggests that its present across both technical and non-technical roles. That said, the root causes might be different: a project manager might feel uncertain because he does not understand the technical context that he must manage, while a software developer might struggle with particularly large, legacy, or poorly written systems. Organizational complexities refer to issues such as communication issues between departments and unclear jurisdictions. Its frequency might be emphasized in this study due to the mentioned high representation of large, international employers amongst the respondents. Similarly, the international context might accentuate the complexities in surrounding environments, as ISD professionals might have to deal with, for example, various technical standards and legislations.

Overall, the five individual sources of uncertainty with the lowest average frequency are related to personal matters, large team size, and use of agile methods. The low frequency for large team and use of agile methods might be partly explained by their situational nature: not everyone works in a large team nor in projects managed with agile methods. Correspondingly, failure handling causes uncertainly conditionally: it can be present only when something fails in a project. Personal matters, such as fear, lack of trust, and personal problems outside of work rarely cause uncertainty for ISD professionals. However, less experienced ISD professionals experience uncertainty due to personal matters and technology evaluation more frequently than their experienced counterparts. More experienced professionals might have built up their professional confidence, while fresh professionals might still be laying the foundation for theirs. As ISD projects often score high on uncertainty and complexity, inexperienced professionals might, for example, fear that asking conspicuous questions would affect others' views on their abilities (Edmondson, 1999), causing uncertainty. In a similar vein, technology evaluation, such as a chosen technology's relevance in the future, was a less frequent source of uncertainty for experienced professionals. If one has worked for more than three years in ISD, one most likely has a better view on how technologies progress across their lifecycles than someone just introduced to such technologies. It could also be that seeing technologies come and go lowers the uncertainty because the process is seen as something natural: no matter how well you evaluate the alternatives and choose your solution, trade-offs and new solutions are going to pop up at some point. In addition, fresh professionals are less likely to have the technical expertise to properly evaluate the different impacts of the technologies.

Outside the divergences discussed in the previous paragraph, it seems that fresh and experienced ISD professionals experience uncertainty due to different sources with similar frequencies. In a vendor-client context, a professional only has limited control over the project, and it might be difficult to reduce the uncertainties where the client is in a key role, even with experience. For example, an ISD professional might become more adept in requirements elicitation during his career, but if there are many conflicting wants or the one giving the requirements doesn't understand software, the effects of the improvement may remain marginal.

Looking at the top-level categories of uncertainty, it's clear that ISD professionals working on the vendor side experience uncertainty from causes stemming from the client organization more frequently than from sources stemming from their own organization. As uncertainty is heavily linked with availability of information, these results hardly come off as a surprise: an employee is much more likely to have clear information and good understanding on the organization he works in, rather than the client organization. In addition, uncertainty has many negative connotations, and the respondents might have been inclined to downplay the uncertainty sources related to themselves or their employer in comparison to the ones related to the client organizations, consciously or unconsciously (Nederhof, 1985).

5.2 Implications for industry

The results suggest that the adopted taxonomy contains sources of uncertainty that are present and relevant in ISD projects. The items can be used as a basis for identifying uncertainty sources in an uncertainty management approach, such as the ones by Ibrahim et al. (2009) and Marinho et al. (2019) introduced in section 2.4. According to the contingency perspective widespread in IS and project management literature, projects with differing levels of uncertainty and complexity should be managed with different project management models (e.g., Moynihan, 2009; Wallace & Keil, 2004). ISD organizations could assess the projects overall uncertainty through these items and their respective frequencies to create an estimation of overall uncertainty related to a new project. This could then guide the selection of a suitable project management model.

The three most frequent sources of uncertainty amongst IS professionals were that new features arise, lacking initial requirements, and that the client doesn't understand software. These results support and reinforce the industry focus on requirements engineering. However, it is important to remember that these uncertainties can also have positive effects. A new feature arising in the middle of a project might be a source of uncertainty, but if that feature is based on information that was not available at the start of the project and improves the system being developed, it might have a positive effect on the project overall. On the other hand, if the clients don't understand software, it is difficult for them to give great, comprehensive requirements. This might lead to lacking requirements and unnecessary changes during the project, not innovation. It's worthy of note that lack of commitment from the client was ranked significantly less frequent source of uncertainty, which indicates that the issue is not in motivation. Therefore, in addition to improving requirements engineering, it might be worthwhile to educate the client on software in the early stages of the project, when appropriate. Interestingly, the counterpart of client not understanding software, the team not understanding the business domain, also scored much lower. Research has revealed that we commonly overestimate our skills at work (Dunning et al., 2004). Even if uncertainty was raised from a situation which could have been avoided if we understood the client's business better, such as translating domain specific requirements, we might mentally attribute it to the client not understanding the software's demands or some other uncertainty stemming from the client organization.

The findings from this study also offer insight into the differences in uncertainty perception by employees with different levels of experience. Companies should look to manage the more frequent uncertainty from fear and technology evaluation felt by inexperienced employees. According to Nembhard & Edmondson (2006) and Bienefield & Grote (2012), a low status is a significant impediment to speaking up. Speaking up can be defined as "discretionary communication of ideas, suggestions, concerns, or opinions about work-related issues with the intent to improve organizational or unit functioning"(Morrison, 2011). That is in line with the results from this study: an employee with only a little experience in ISD is more likely to have a low status within the organization, leading to impediments to speaking up and increased uncertainty due to fear. Grote (2015) argues that by supporting the employees speaking up in uncertain situations companies can reduce the adverse effects of uncertainty and increase the likelihood of positive ones. Researchers have found that inclusive leadership and psychosocial safety play a key role in encouraging employees to speak up. Inclusive leaders make an explicit effort to invite others' input and show their appreciation for others' contributions. (Nembhard & Edmondson, 2006) In teams with psychological safety, the team members believe that the team is safe for interpersonal risk taking. In practice this means that the team will not ridicule, reject, or punish a member for speaking up. (Edmondson, 1999) The benefits from speaking up have been shown in organizational learning and innovation (Edmondson, 2003), as well as safety (Kolbe et al., 2012). In ISD context, inexperienced employees might face uncertainty due to fear in, for example, situations where they are following instructions but do not fully understand the meaning or consequences of those actions to the system. We suggest that companies working in ISD should experiment with supporting speaking up through the abovementioned methods, especially in projects and teams with professionals just starting out their careers. Concrete actions that companies can take include, for example, structured debriefings, two-challenge rule (Pian-Smith et al., 2009), and training for team leaders (Grote, 2015).

5.3 Limitations and threats to validity

The taxonomy of uncertainties adopted for this study from Taipalus et al. (2020) was devised from interviews with ten ISD professionals. The relatively small sample size means that the taxonomy might not represent the whole breadth of uncertainty sources for ISD professionals. As Dönmez & Grote (2018) noted on their study, people often interpret the sources of uncertainty in different ways. It is likely that the respondents have been thinking of different definitions of the constructs while answering the survey. Additionally, the negative perspective of uncertainty is far more common than the positive perspective in the minds of the general public. Therefore, while this study defines uncertainty as something that's not inherently negative or positive, some respondents might have been thinking about negative experiences exclusively. Even though we made a conscious effort to assure participants of their answers' anonymity, it might be that the nature of the study brought up social desirability bias. Professionals might be less inclined to report uncertainty that could be seen to reflect negatively to themselves or their employers (Nederhof, 1985).

This study is limited by its focus on the vendor side perspective of ISD, which was chosen to better align it with the uncertainty sources from Taipalus et al. (2020). Professionals working on the client-side of ISD might experience different uncertainties or experience the same ones with different frequencies.

As all the respondents worked in Finland, the results might not be generalizable to ISD professionals working in other countries, and, therefore, in possibly very different environments. For example, working cultures in specific countries could exacerbate uncertainty caused by certain sources. Additionally, majority of the respondents work in large (over 250 employees) companies that operate internationally. Smaller ISD vendors might experience certain uncertainty sources at different frequencies, and some, such as "large teams", might even not be applicable to the smallest companies.

Because we didn't have a scientific basis for the exact group division to those with less than three years of ISD experience and those with more than three years of ISD experience for the Mann-Whitney U test, it poses a threat to the results' validity. However, to counteract this threat, we utilized Spearman's rank-order correlation to assess the relationship between the perceived frequency of uncertainty due to a source of uncertainty and years of ISD work experience. The results from the Spearman's correlation were similar to those from the group-based tests and supported the validity of our group division.

5.4 Further research

While this study sheds light on the frequency of the different sources of uncertainty, it cannot answer for the significance of each source to the success (or failure) of a project. An uncertainty source might be often present in projects but have a minor impact on the project's success. Imagine you are walking in a forest to gather berries and mosquitoes are biting you the whole time. On the other hand, an uncertainty source might manifest rarely, but when it does it has a major impact on the project. Like stepping between a bear and its cub during your berry-stroll. The knowledge around this list of uncertainty sources could be further improved by relating the sources of uncertainty to specific project outcomes, such as budget or schedule overruns (Barki et al, 1993). Alternatively, the impact could be studied through a subjective view on the difference the manifestation of uncertainty from each source makes to the overall success of the project. Moynihan (1999) studied how the manifestation of specific risk constructs affects the overall "riskiness" of an IS project. 20 IS/software project managers were asked to rate whether the manifestation of a construct would have a very big difference, big difference or little to no difference to the project riskiness. Similar research for the sources of uncertainty discussed in this study would complement the information on their occurrence. Together, such knowledge could be used by industry practitioners to better estimate the total impact of certain uncertainties in their ISD projects.

Another interesting perspective would be to study whether the perception of specific uncertainty sources is different for people working mainly on the business/management side of an ISD project and those participating in the technical implementation. Understanding the deviations between perspectives might help to build a more complete picture of uncertainty in projects, as well as the possible biases and blind spots each side has. If there are significant deviations between these groups, it might shed light on why resourcing and scheduling ISD projects is extremely challenging. For example, drilling on uncertainty caused by complex technical environments through qualitative research could help answer the speculation on role-specific root causes in the previous section.

The study design used here could be repeated in different contexts to see whether the results would align. For example, further studies could be conducted in countries other than Finland, on organizations of specific size (small, large), or focusing on specific type of information systems. In our opinion, this is just a start for empirical research on sources of uncertainty in ISD context. There are several high value research avenues that can branch from here, building a better understanding of uncertainty in ISD.

6 CONCLUSION

We set out to find out due to which sources is uncertainty most frequently felt by ISD professionals in ISD projects and how does the frequency of uncertainty felt due to specific sources differ between experienced ISD professionals and their less experienced counterparts. We adopted the taxonomy of 24 sources of uncertainty and the vendor-side perspective from Taipalus et al. (2020). The results from the survey of 64 ISD professionals showed that ISD professionals working on the vendor side in ISD projects most frequently felt uncertainty due to new features arising during development, lacking initial requirements and clients not understanding software. Even though the frequency of uncertainty felt due to specific sources had not been previously researched in IS context, the results are in line with prior research in a sense that these items have been noted as significant sources of uncertainty. ISD professionals with less experience feel uncertainty due to fear, technology evaluation, and personal matters more often than their more experienced colleagues. The results suggest that ISD professionals with varying levels of experience uncertainty from the other sources with similar frequencies. Finally, we suggest several research considerations and implications to industry practitioners, as well as opportunities for further research.

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APPENDIX 1 SURVEY QUESTIONS

Background and demographic questions

1. What is your current job title?
2. In which country do you work in?
3. In which industry does your company operate?
4. Select the option that best describes the size of your company?
   a. Less than 10 employees
   b. 10 to 49 employees
   c. 50 to 249 employees
   d. 250 to 1000 employees
   e. More than 1000 employees
5. Does your company conduct information system development projects for business clients?
   a. Yes
   b. No
6. Does your company conduct business internationally?
   a. Yes
   b. No
7. Have you worked in an information systems development project on the vendor side during the past 3 months?
8. How long have you been working with information system development?

Sources stemming from within the development organization

1. In your projects during the previous three months, how often have you felts uncertainty due to …

1 = Never, 2 = Rarely, 3= Sometimes, 4 = Often, 5 = Almost always

Lack of trust
Fear (e.g. of asking clarifying questions)
Personal problems outside work
Large team size
Lack of knowledge concerning roles
Unsuitable communication channels
Different personal working methods
Use of agile methods
Lack of specific compétences in the team
Inconsistent resource allocation
Organizational complexities
Failure handling

Sources stemming from the client organization

1. In your projects during the previous three months, how often have you felts uncertainty due to …

1 = Never, 2 = Rarely, 3= Sometimes, 4 = Often, 5 = Almost always

Client doesn’t understand software
Team doesn’t understand the business domain
Lacking initial requirements
New features arise
Lack of commitment from the client
Authority-involvement discrepancy (e.g. people making most of the decisions regarding the system are the ones using the system the least)
Prioritization of conflicting client wants
(e.g. different stakeholders want and need different features and prioritize them differently)

Sources stemming outside the development and client organizations

1. In your projects during the previous three months, how often have you felts uncertainty due to …

1 = Never, 2 = Rarely, 3= Sometimes, 4 = Often, 5 = Almost always

Complex technical environments
Technology evaluation (e.g. the relevance of the technology in the future)
Changes in surrounding environments
Complexities in surrounding environments
Lack of suitable workforce on the market

APPENDIX 2 CHANGES TO ORIGINAL TAXONOMY ITEMS

Original item	Modified item	Reasoning
Fear	Fear (e.g., of asking clarifying questions)	Added example to clarify a broad term
Agile methods	Use of agile methods	Better suited for question formulation
Incompetence	Lack of specific competences in the team	Without context the original item could be interpreted as incompetence of the person answering the survey
Authority-involvement discrepancy	Authority-involvement discrepancy (i.e., people making most of the decisions regarding the system are the ones using the system the least)	Added description because the original terminology might be unfamiliar to respondents
Prioritization	Prioritization of conflicting client wants (i.e., different stakeholders want and need different features and prioritize them differently)	Unclear object of prioritization
Technology evaluation	Technology evaluation (e.g., the relevance of the technology in the future)	Added example to clarify a broad term
Lack of suitable workforce	Lack of suitable workforce on the market	Changed to better convey the meaning in the original study