Table 1. Specification of a TSD-type and an ASD-type sample project

Base costs input parameters				Risks TSD-type project			Risks ASD-type project		
a	2.94	SF_5	6.24		TSD mode	ASD mode		TSD mode	ASD mode
B	0.91	EM_i	1						
G	3.67	C_{Dev}	5,000 MU	μ_{DEF}	1.5 %	4 %	μ_{DEF}	1 %	2 %
D	0.28	c	0.15	μ_{CHG}	1.25 %	0.5 %	μ_{CHG}	2.5 %	1.5 %
SF_1	3.72	e	0.05	μ_{DEL}	1.25 %	0.5 %	μ_{DEL}	2.5 %	1.5 %
SF_2	3.04	f	0.4	σ_{DEF}	5 %	30 %	σ_{DEF}	5 %	15 %
SF_3	4.24	Sprints	2 per mo.	σ_{CHG}	15 %	10 %	σ_{CHG}	22.5 %	10 %
SF_4	4.38	$Size$	$size$	σ_{DEL}	15 %	10 %	σ_{DEL}	22.5 %	10 %

Table 2. Sample correlations between risk types for TSD and ASD mode

TSD mode				ASD mode			
$\rho_{i,j}$	DEF	CHG	DEL	$\rho_{i,j}$	DEF	CHG	DEL
DEF	1	0	0.5	DEF	1	0	0.25
CHG	0	1	0.5	CHG	0	1	0
DEL	0.5	0.5	1	DEL	0.25	0	1

We first analyze the ASD-type project from Table 1 and choose a constant absolute risk aversion $\alpha = 0.0002$. This is reasonable according to Bamberg and Spremann [37]. Figure 2 (left chart) illustrates the results, where we show different deltas between TSD and ASD mode in terms of costs, risk, and risk-adjusted costs while varying the project size between 0 and 300 KSLOC. The dotted line depicts the delta in terms of costs, the dashed line depicts the delta in terms of risk, and the continuous line depicts the delta in terms of risk-adjusted costs.

As outlined, the cost advantage for ASD is only given for small projects. The initial effort required for accomplishing a small number of sprints in ASD mode is relatively small compared to the overhead of upfront planning in TSD mode. With larger project sizes, the initial planning effort in TSD mode increases less than the overhead for planning larger amounts of sprints in ASD mode. Thus, TSD has a cost advantage for larger project sizes. This finding in our sample calculation complies with extant knowledge. Researchers have argued that TSD mode is more favorable for large projects in general [38]. From a risk perspective, ASD is the preferable SD mode for all investigated project sizes between 0 and 300 KSLOC. The risk advantage for ASD always exceeds the cost advantage for TSD mode. Therefore, ASD is the appropriate mode for the sample project at hand. For decision-makers with a lower level of risk aversion (α), the delta between TSD and ASD in terms of risk-adjusted costs is depicted by the continuous grey line in Figure 2 (left chart). In this case, ASD is not favorable for all project sizes. In case of more risk-seeking decision-makers, the cost advantage for TSD exceed the risk advantage for ASD for large project sizes. This example illustrates that deciding on the SD mode is similar to balancing the certain cost advantage of TSD against the risk advantage of ASD. Economically speaking, decision-makers charge a risk premium for requirements changes on the safe cost advantage for TSD mode.

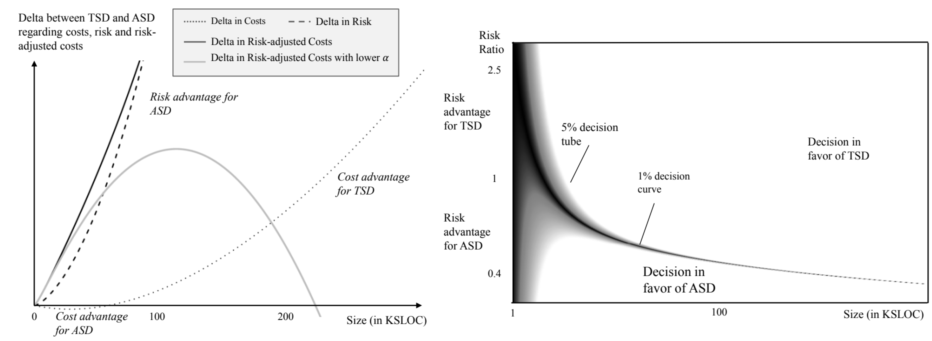

Figure 2. Calculation for the ASD-type sample project and grey-scale plot of relative delta

Next, we analyze the TSD-type project from Table 2. Table 1 shows the correlation coefficients of the risk types for both modes, which we use for our calculations. For both modes, the risk of defect is positively correlated with the risk of delay. As TSD is not as adaptive and flexible as ASD, a defect in TSD has a larger impact on the risk of delay compared to ASD. For TSD, a change of requirements increases the risk of delay, as heavy planning does not allow for changes. ASD mode can cope much better with changed requirements. As a consequence, the risk of requirements changes and risk of delay are uncorrelated in ASD mode. The cost advantages of TSD and ASD are the same as for ASD-type project, as the input parameters for the base costs are independent of the SD mode. Further, the risk advantage of TSD is positive for all project sizes, making TSD the preferable mode for nearly all project sizes. With the above examples, we demonstrated the suitability of our decision model by conducting sample calculations for a TSD- and an ASD-type sample project.

To demonstrate the robustness of our decision model, we now analyze the delta in risk-adjusted costs between both SD modes by varying the size and risk structure of a given project using a sensitivity analysis. When setting up the sensitivity analysis, two features must be considered: First, to stay comparable with an increasing project size, we rely on the relative delta in risk-adjusted costs, i.e., we divide the absolute delta in risk-adjusted costs by the absolute risk-adjusted costs of the respective SD mode. We do not consider the absolute risk-adjusted costs delta, which gets biased with an increasing project size. Second, as we only have a single dimension for describing the risk structure, we divide the risk of defect, which is typical for TSD-type projects, by the sum of the risk of requirement changes and delay, which are more typical for ASD-type projects. Thereby, we get a risk ratio that indicates a risk profile in favor of ASD for values from the interval $[0,1[$ and in favor of TSD for values from $]1,\infty[$. As a result, we get a three-dimensional analysis with project size and risk ratio on the horizontal and vertical axis, and the delta in relative risk-adjusted costs as a grey-scale plot. The delta in relative risk-adjusted costs is depicted on a grey-scale with bright indicating a high delta and dark indicating a low delta. The dark area shows settings where decision-makers are indifferent, whereas the bright areas illustrate robust decisions in favor of either TSD or ASD. We start with the TSD-type project from Table 1. We then reduce the risk of defect successively, while equivalently increasing the risk of requirement changes and delay until we end up with the ASD-type project from Table 1. This way, we get comparable projects regarding costs and a balanced risk profile half way between both projects (i.e., risk ratio = 1). The black area and line in Figure 2 (right chart) shows the decision curve, i.e., the area of indifference between both SD modes. Along the decision curve, the relative delta in the risk-adjusted costs is less than one percent. The grey decision tube around the black line depicts the delta values that are less than five percent of the respective risk-adjusted costs. Within this tube, the decision is not profound, but slightly tends to one of both modes. Decision-makers have to be careful regarding decisions within the five percent decision tube, as estimation errors may strongly influence the decision. For small projects, the decision is mainly influenced by the risk advantage of TSD or ASD depending on the SD mode, since the cost advantage of ASD is negligibly small. The black area indicates that our decision model is indifferent for small projects as it strongly depends on the risk distribution of the project at hand and the SD modes. However, this indifference is plausible, as the decision on the appropriate SD mode for a small SDP does not carry as much weight in terms of total costs as for large SDPs. The managerial implication is that decision makers should focus on finding the appropriate mode for larger SDPs, since for small projects the cost and risk difference is negligibly small. With an increasing project size, the costs are strongly in favor of TSD mode, leading to a steep decrease of the decision curve. The decision curve then converges towards the horizontal axis, indicating a larger area for unambiguous decisions in favor of TSD for very large projects. This is due to the cost advantage of TSD. That is, it can be reasonable from a cost/risk perspective to implement an SDP in TSD despite a risk advantage for ASD mode. For strongly ASD-type SDPs, i.e., projects with a very strong risk of requirement changes and delays, however, ASD is appropriate. The managerial implication of this finding is that decision makers should carefully evaluate the project's risk in both modes, since it could reverse a strong cost advantage for large projects. Although the graph in Figure 2 indicates otherwise, there is no reason to believe that the majority of projects should be conducted in TSD mode. First, SDPs in practice are not equally distributed over the size and risk dimensions. Second, we analyzed only one particular sample SDP in Figure 2. In a practical setting, our model primarily serves as decision support. Decision-makers should nevertheless carefully evaluate the outcome by taking their experience and other models into account.

5 Conclusion

In this study, we investigated how organizations can decide whether to implement a distinct SDP in TSD or ASD mode. Building on the characteristics of the SDP in focus and the characteristics of both SD modes, we proposed a decision model that analyzes the costs and risks associated with the implementation of a distinct SDP. Our model builds on the cost estimation method COCOMO II for TSD mode and the extensions proposed by Benediktsson et al. [24] for ASD mode to achieve comparability between both SD modes. To extend a purely cost-based view, the model accounts for three major risk types related to the implementation of an SDP, i.e., risk of defect, requirement changes, and delay. Besides these risk types, the decision model incorporates sprint length and overhead costs as characteristics of TSD and ASD mode. Our contribution is twofold. First, we bring the two cost estimation approaches together. Second, we extend the solely cost based view by a risk perspective. As for evaluation, we applied the decision model to sample projects with different input parameters. We also conducted a sensitivity analysis based on a software prototype to validate the decision model's suitability and robustness. The sensitivity analysis corroborated that the decision model yields plausible results. Overall, we contribute to the prescriptive knowledge on software development with a decision model as concrete artifact and its instantiation as a software prototype.

Our decision model is beset with limitations. First, we assume the risk types to be independent over time and normally distributed. Thus, the decision model underestimates risks associated with implementing an SDP. Risks may also increase or decrease over time, e.g., the expected additional costs for a change in requirements may increase over time if the project is executed in TSD mode. Research on inter-temporal dependencies of SD risks is required to implement these effects into our decision model. Future research should explore the risk structure of SDPs. Second, the decision model focuses on costs and risks that accrue during SDP implementation. Considering an SDP's business value also requires integrating benefits. In ASD mode, design and run time can no longer be separated as benefits accrue after each sprint. In TSD mode, however, benefits only realize after the SDP has been fully completed. Thus, we recommend that further research extends the decision model toward a cost-benefit analysis that includes benefits and a runtime perspective. Third, we focused on individual SDPs, ignoring the portfolio perspective. Future research should investigate how project dependencies influence the TSD/ASD trade-off. Fourth, as a first step, we demonstrated and analyzed the decision model via sample projects and a sensitivity analysis. Thus, the decision model would benefit from naturalistic evaluation, e.g., real-world case studies.

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