Descoping

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Abstract

Descoping is the strategic abandonment and/or weakening of objectives. It is required whenever limited resources preclude satisfactory attainment of all those objectives. Potential causes of the need for descoping are numerous, and descoping is a recurring phenomenon during project planning and development.

We present an approach which facilitates descoping. It is founded upon a quantitative model of requirements attainment, resource consumption, and risk. Features of this model allow for the representation of interactions between objectives. Measures derived from this qualitative model support the identification and evaluations of descope options. Tool support for the model gives assistance to users in making their descope decisions.

The purpose of this extended abstract is to outline the problem context, and summarize the salient features of our approach to assisting descope planning.

Keywords

Descoping, tradeoffs, requirements prioritization, requirements triage, release planning, quantitative models, risk management, requirements interaction management, requirements engineering.

1. Introduction

Determining the objectives (a.k.a. requirements) is widely recognized as one of the crucial early steps in project planning. In almost all cases the objectives must be balanced against the costs of attaining them - it is rare that objectives are committed to no matter what their cost. Cost limitations force selection of the subset of objectives to be pursued. Later in the lifecycle, deviations from the planned development process lead to the need to revisit this selection. Schedule slippages, cost overruns, and requirements changes can each contribute to this. Under fortuitous circumstances, an *increase* in objectives could be feasible, but the much more common situation is to need to descope further. For the purposes of this paper, the word "descope" is intended to cover both kinds of down-selection, both during initial planning, and during the course of development.

Section 2 describes the challenges of descoping, and past work in this area. Section 3 introduces the quantitative risk-based model that serves as the basis for our investigations of descoping. Section 4 presents the ways in which this model supports in-depth descope planning. Section 5 offers a conclusion, and some suggestions for future work.

2. Descoping Challenges

To descope effectively requires cost estimation (how much it will cost to attain a given set of objectives) and valuation (what is the end value of attaining a given set of objectives). These are both research areas in which there has been substantial progress. For example, COCOMO [Boehm et al, 2000] helps predict costs once the overall project characteristics (both product characteristics, and development process characteristics) have been estimated. Accord [Ullman, 2001] helps groups of people achieve consensus on the preferred set of objectives.

Descoping is complicated when objectives interact (i.e., when they are interdependent, so that an objective cannot be considered in isolation of all the other objectives). Such interaction appears to be commonplace. [Carlshamre et al, 2001] report a study in which they found interdependencies to be the norm in their setting (Ericsson Radio Systems). Robinson et al [Robinson et al, 1999] employ the term "requirements interaction management" in their survey of the broad range of studies in this area.

Other terms for what we are here calling "descoping" include "requirements prioritization", "requirements triage" [Davis, 2000], and (especially in the context of commercial software products) "release planning". Examples of tool-supported approaches that assist in this area include: the cost-and-value based approach [Karlsson & Ryan, 1997], the "negotiated win conditions" of [Boehm et al, 1994], the explicit treatment of non-functional requirements in evaluation alternatives as part of the i* approach [Mylopoulos et al, 2001].

Our setting, that of spacecraft design and operation, faces these same pressures. We are resource constrained – NASA's budget must be allocated to best achieve science return; launch vehicle capacities constrain mass and volume; solar panels can yield only so much electrical power. We too are often schedule constrained – albeit not because of economic pressures to be first to market, but because of cosmological factors that favor certain launch windows (e.g., proximity in orbit between Earth and Mars). Spacecraft introduce yet another complication - risk. Risk is unavoidable in our setting, due to the potential for irreparable hardware failures, unpredictable aspects of the environment, lack of detailed and/or current knowledge of the spacecraft state (because of limited communications bandwidth and long round-trip light times), and the sheer complexity of their multi-disciplinary development. This forces the consideration of not only *which* objectives to select, but also *how diligently* to pursue them. [Greenfield 1998] recognized the need to trade risk itself as a resource, alongside other key factors in spacecraft development (e.g., cost, schedule, mass, power).

3. A risk-based cost-benefit model

The basis for our investigations is a quantitative risk-based model that we have been developing at JPL. This model, called "Defect Detection and Prevention (DDP)", has been applied to help assess and plan developments of novel spacecraft technologies and systems [Cornford et al, 2001], [Cornford et al, 2002]. We have reported on this model in other publications, so here will focus on only its aspects relevant to descoping.

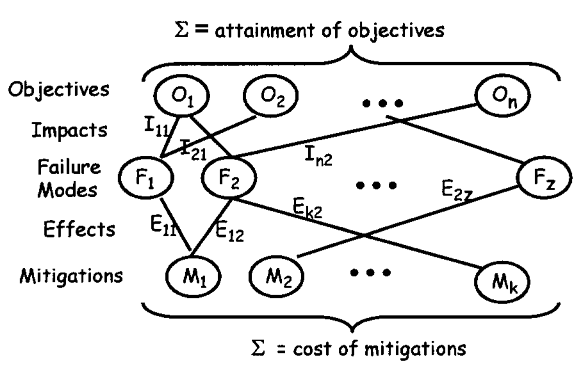


Figure 1. Topology of DDP's risk-centric cost-benefit model

The topology of DDP's risk-based model is sketched in Figure 1. *Objectives* (O1, O2, ...) are given weights, reflecting their relative importance. *Failure Modes* (F1, F2, ...) are all the things that, should they occur, have adverse *Impacts* on Objectives. These Impacts are assigned numerical strengths, indicating how much of the Objective would be lost should the Failure Mode occur. *Mitigations* (M1, M2, ...) are all the things that should they be applied, have a reducing *Effect* on the likelihood and/or impact of Failure Modes. These Effects are assigned numerical strengths, indicating by how much the likelihood and/or impact of the Failure Mode will be reduced should the Mitigation be applied.

The *cost* of a DDP model is the sum of the costs of the Mitigations selected for application. The *benefit* of a DDP model is the sum of attainment of its Objectives, calculation of which takes into account the Failure Modes' impacts on those Objectives, moderated by the reducing effects of the selected Mitigations on those Failure Modes.

4. Descoping

The primary purpose of a DDP model is to guide selection of Mitigations. In our studies, sum total cost of the available Mitigations exceeds the resources available, so the challenge has been selection of a subset of those Mitigations that maximize attainment of Objectives while remaining within resource limits. Descoping is needed when resource limits preclude the complete or near-complete attainment of Objectives.

The subsections that follow detail the key ways in which the DDP model and its software faciliate user descope decision making:

- The model's explicit and detailed treatment of interactions.
- The various quantitative measures that reveal different aspects of descope needs.
- Visualization to permit users to see the ramifications of those measures.
- Optimization to direct users towards descope options worth of particular attention.

4.1. An explicit and extensible model of interactions

Interactions arise in our DDP model through the Impact and Effect connections. These cross-couple Objectives, Failure Modes and Mitigations. For example, a Failure Mode may impact multiple Objectives (and to different degrees). The selection of a Mitigation may thus effect multiple Failure Modes, reducing their impact on multiple Objectives. This explicit treatment of cross-coupling is at the heart of the DDP model. In contrast, other approaches to handling interactions have tended to follow the route of eliciting pairwise couplings directly between the objectives themselves (e.g., the “interdependencies” of [Carlshamre et al, 2001]).

Each of these classes of DDP’s objects are user-extensible. For example, new kinds of Failure Modes can be added on-the-fly, and coupled to Objectives and Mitigations. This allows the DDP model to capture a very wide variety of interactions.

4.2. Quantitative measures of attainment, and their role in descope planning

The DDP model defines several quantitative measures. The key such measures relevant to descoping are outlined next. Space limitations preclude a formal definition in this extended abstract.

Objective’s degree of attainment: defined for each objective as the proportion of that objective attained. Its definition takes into account the adverse impact of all extant Failure Modes and the reducing effects on those of all selected Mitigations.

All objectives sum total attainment: defined for the entire model as the sum, over all objectives, of each objective’s weight times its degree of attainment. This is the overall “value” measure of a DDP model.

Objective’s degree of risk: defined for each objective as the proportion of that objective impacted by all extant Failure Modes, taking into account the reducing effects of all selected Mitigations. In the DDP model, it is possible (indeed common) for an objective’s degree of risk to be *greater* than 1.0. This indicates an objective adversely impacted by several Failure Modes, so much so that they more than completely eliminate attainment of that objective.

The objective’s degree of attainment measure gives an indication of how well an individual objective is being attained. This measure is used to understand which objectives are being attained, and by how much, given a DDP model’s configuration (set of Failure Modes and selection of Mitigations). Objectives that are being completely, or nearly completely, attained are low-risk items that we can have confidence will likely be met.

The sum total attainment measure gives an indication of the overall value of a DDP model as currently configured. This can be used to compare major alternative descope options.

The objective’s degree of risk measure gives an indication of how much work needs to be done to attain an objective. For an objective that is less than totally eliminated by risks from Failure Modes, this is the complement of its degree of attainment measure. That is, under those circumstances, degree of attainment = (1 – degree of risk). However, when an objective is more than totally eliminated by risks from Failure Modes, its degree of attainment will be zero, while its degree of risk will be greater than 1. This degree of risk measure is important to understanding how implausible an objective really is. One that is just slightly over 1.0 at risk is a candidate for improvement (by selection of additional Mitigations to reduce the Failure Modes impacting that objective), but one that is well over 1.0 at risk is a strong contender for descoping.

4.3. Visualization support for exploring descope options

The DDP software supports users in their exploration of descope options.

Users can change the selection of mitigations and see the ramifications on all the automatically calculated measures. DDP’s visualizations are cogent displays designed to convey the status of these measures.

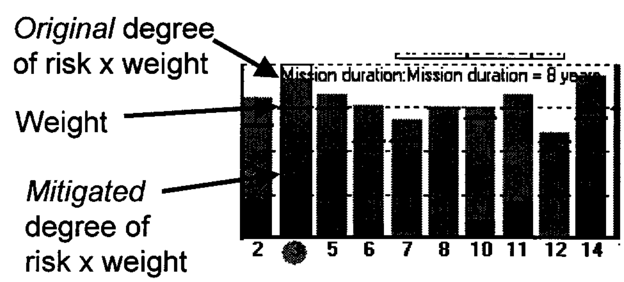


Figure 2. DDP display of various measures of objective attainment

A snapshot from an actual DDP display is shown in Figure 2. Each of the bars corresponds to an objective in a spacecraft technology study. Consider the second one from the left (with the blue circle highlighting its number 3), which is the objective that the mission duration be 8 years. Prior to the selection of any mitigations whatsoever, its original degree of risk x its weight was very high, indicated by the height of the green column. The blue bar indicates its weight. Its position *below* the top of the green column indicates that originally it was more than totally at risk. However, given the current selection of mitigations, its degree of risk x its weight (indicated by the height of the red column) is significantly reduced, so in fact it is quite likely that it will be attained.

4.4. Optimizing the attainment of objectives

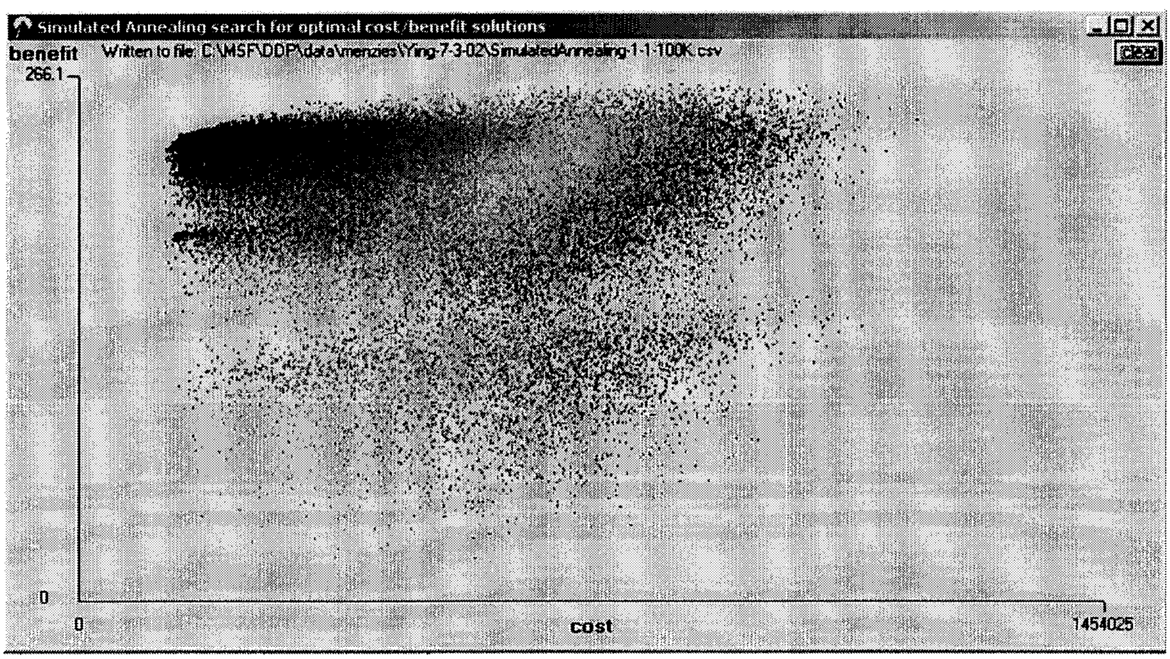
DDP's calculation of costs and benefits permit treatment of the cost/benefit tradeoff as an *optimization* problem. A cost ceiling can be set, and optimization techniques used to find the selection of mitigations that maximize the sum total of objectives' attainment while remaining at or below the cost ceiling. Alternately, an attainment floor can be set, and optimization techniques used to find the least costly selection of mitigations that lead to attainment of at least that much total objectives' attainment.

For our spacecraft technology applications, DDP models are quite large. It is typical to see dozens to hundreds of Objectives, Failure Modes and Mitigations, and hundreds to thousands of Impacts and Effects between them. We use heuristic search techniques to effectively explore the large search space of Mitigation selections. We have had success using both genetic algorithms, and simulated annealing. We have also collaborated with Tim Menzies to apply his machine-learning based technique, which has proven capable of both finding near-optimal solutions, and identifying the Mitigations whose selection (or non-selection) are most critical to get those solutions [Feather & Menzies, 2002]. More details on our use of heuristic search can be found in [Cornford et al, 2003].

Shown below is an illustration of simulated annealing applied to optimizing an actual DDP spacecraft technology model. The horizontal axis of the plot corresponds to cost, the vertical axis to benefit (sum total attainment of objectives). Thus the optimum is to be found towards the upper left corner. Simulated annealing's progress towards this corner is shown by the spectrum from red ("hot") through orange, yellow, green and blue ("cold").

Optimization runs such as this help uses understand descope options in three ways:

- They show users the cost/benefit space. The boundary points that delineate the area are of special importance, since they give an indication of feasible near-optimal alternatives at different points along the cost/benefit tradeoff.
- Specific near-optimal solutions for the selected cost/benefit tradeoff goal are identified. (In this run, the goal was to strike an even



balance between the two, hence the convergence towards the corner of the space.) Users can then manually scrutinize those solutions (using the bar chart display shown earlier) to see which objectives are being attained, and to what extent, and which objectives are being left unattained. They can, of course, manually adjust those solutions further.

- In near-optimal solutions that attain lower cost by benefit reductions, one or more objectives are under-fulfilled, or even completely unattained. Optimization is automatically locating objectives whose omission would achieve descope needs.

These aspects of the DDP model and its software work well in combination. The detailed and extensible quantitative risk model is the basis; decsope-related measurements are computed from this; visualizations present the information in ways palatable to human scrutiny; automation helps in exploring the large space of options.

5. Conclusions and future work

We have outlined the descope problem. In our context of spacecraft development, we face many of the same pressures on project development as are common elsewhere (severely limited schedules, budgets and other resources). In addition, we must explicitly deal with risk. All these factors combine to make descope a recurring need.

The quantitative risk-centric model we have used for risk management is well suited to in-depth consideration of descope options and their implications. It has a detailed model of interactions among objectives, failure modes (risks), and mitigations. Quantitative measures defined in terms of that model give insight into opportunities for, and consequences of, descopes. Cogent visualizations inform project managers of this information, facilitating their strategic decision-making. Automated optimization (using heuristic search techniques) finds descope opportunities along the near-optimal boundary of the cost-benefit trade space.

Taken together, these capabilities provide significant support for strategically planning descopes. We see the need for further work in the areas of:

- Enhanced interplay between the optimization / search techniques, and human-guided decision-making. For example, allow users to impose additional constraints on the solution sets they are willing to accept, and re-optimize taking those into account. Out collaborative work with Tim Menzies [Feather & Menzies, 2002] has an aspect of this. The work of [Menzies & Hu, 2001] suggests opportunities for more such benefits.
- Exploration of descope options that, rather than discard objectives, change their relative weights. For example, suppose a mission with primary and secondary science return objectives needs to be descoped; rather than discarding one of those objectives, perhaps the descope needs can be met be reversing their prioritization? The New Millenium missions [Minning at al, 2000], each designed to flight validate advanced technologies, would be promising application areas for this.

The status of our work is that the DDP model has been used on numerous studies of spacecraft technologies. Although we did not approach those studies with descoping of objectives in mind, it is interesting to note that some of them led to descope decisions. In retrospect, we see descoping as a recurring phenomenon, and are encouraged by DDP's ability to assist in this. Future work will, we hope, further extend its capabilities in this direction.

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7. References

[Boehm et al, 2000] B. Boehm, C. Abts, A.W. Borwn, S. Chulani, B.K. Clarl, E. Horowitz, R. Madachy, D. Reifer & B. Steece. "Software Cost Estimation with COCOMO II", Prentice-Hall, July 2000.

[Boehm et al, 1994] B. Boehm, P. Bose, E.

Horowitz, and M. Lee, 1994, "Software Requirements as Negotiated Win Conditions", Proceedings 1st International Conference on Requirements Engineering, Colorado Springs, Colorado, pp. 74-83.

[Carlshamre et al, 2001] P. Carlshamre, K. Sandahl, M. Lindvall, B. Regnell & J. Natt och Dag. "An Industrial Survey of Requirements Interdependencies in Software Product Release Planning", *5th IEEE Int. Symposium on Requirements Engineering*, 2001, pp. 84-91.

[Cornford et al, 2001] S.L. Cornford, M.S. Feather & K.A. Hicks. "DDP – A tool for life-cycle risk management", *IEEE Aerospace Conference*, Big Sky, Montana, Mar 2001, pp. 441-451.

[Cornford et al, 2002] S.L. Cornford, J. Dunphy and M.S. Feather, 2002, "Optimizing the Design of end-to-end Spacecraft Systems using Risk as a Currency", IEEE Aerospace Conference, Big Sky, Montana, Mar 2002.

[Cornford et al, 2003] S.L. Cornford, J. Dunphy, M.S. Feather and J. Salcedo, 2002, "Heuristic Optimization for Risk Reduction in Spacecraft Designs", submitted to the 2003 IEEE Aerospace Conference, Big Sky, Montana.

[Davis, 2000] Davis, Al. "The Most Ignored Piece of Requirements Engineering: Requirements Triage" *ICRE 2000 Tutorial.* Omni-vista inc., Colorado Springs, CO.

[Feather & Menzies, 2002] Feather, M.S. & Menzies, T. "Converging on the Optimal Attainment of Requirements", to appear in the Proceedings of the IEEE Joint International Conference on Requirements Engineering, Essen, Germany, Sept. 2002.

[Greenfield, 1998] M.A. Greenfield "Risk Management 'Risk As A Resource' " http://www.hq.nasa.gov/office/codeq/risk/

[Karlsson & Ryan, 1997] J. Karlsson & K. Ryan. A Cost-Value Approach for Prioritizing Requirements. *IEEE Software*, Sept./Oct. 1997, 67-74.

[Menzies & Hu, 2001] T. Menzies & Y. Hu. "Constraining Discussions in Requirements Engineering via Models", *1st International Workshop on Model Based Requirements Engineering*, San Diego, California, Dec 2001.

[Minning at al, 2000] C. P. Minning, M. G. Buehler, T. Fujita, F. Lansing, G. Man, A. Aljabri, and C. Stevens, "Technology Selection and Validation on New Millennium Flight Projects," IEEE Aerospace Conference, Big Sky, Montana, Mar 2001

[Mylopoulos et al, 2001] J. Mylopoulos, L. Chung, S. Liao, H. Wang, and E. Yu, 2001, "Exploring Alternatives during Requirements Analysis", IEEE Software 18(1), pp. 92-96.

[Robinson et al, 1999] W.N. Robinson., S. Pawlowski & S. Volkov. "Requirements Interaction Management", GSU CIS Working Paper 99-7, Georgia State University, Atlanta, GA, August, 30, 1999.

[Ullman, 2001] D. Ullman. "12 Steps to Robust Decisions: Building Consensus in Product Development and Business", Trafford Publishing, 2001.