A Practical Way for Projects to Visualize Design Rationale

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Abstract

Design rationale remains poorly explained and rarely modelled on projects in industry. However, the reasons for design decisions are important when a specification has to be re-examined, eg for reuse, for safety, for validation, or to satisfy stakeholders that a project is justified. A practical notation must be extremely simple but expressive, given industry's reluctance. This paper illustrates how a minimal box-and-arrow notation is sufficient for modelling Toulmin argumentation, and helpful on transportation projects. These critically depend on properly documented rationale as they are subject to public inquiry. The use of Dewar signposts to connect such rationale models to changing events in the world is illustrated.

Keywords--- **Rationale, Assumption, Argument, Visualization, Toulmin Argumentation, Dewar Signpost, Goal, Warrant, Rebuttal, Requirement, Transportation**

1. Introduction

As understood by people on industrial projects, 'Requirements' have gradually evolved in meaning from a basic list of 'The system shall' statements, to a mix of goals, scenarios, interface definitions and other constraints. One cause of this was the introduction of use cases [1]. This coincided with the start of research in 'requirements engineering' in the early 1990s, though dissemination of research findings to industry still seems slow.

A requirements specification is therefore starting to be understood in industry as a network of inter-related items, in other words as a data structure rather than a document. This understanding has been encouraged by a third development, the introduction of commercial 'requirements management' database tools. The market leader, DOORS [2], for example, was launched in about 1993. A typical database contains a mix of requirements, definitions, and scenarios, connected by all-important traces (database links). Larger projects may build elaborate databases including all the above, and also goals, issues, risks, tests, and various analysis diagrams such as flowcharts, class models and (design) structure charts, connected by a rich pattern of traceability.

Rationale seems to be rather a poor relation to these other requirements components. The most common representation in a database tool is a simple text field in a column beside a requirement. In a document, rationale is often relegated to italicised comments, or even to undifferentiated introductory text, where it is hard to find – so it is rarely traced to. In consequence, the reasons for major project decisions – which requirements to include, what design approaches to take, which risks to accept – are documented in random ways, or in none.

Why is rationale such a Cinderella compared to requirements and use cases?

- Firstly, rationale is clearly secondary to the thing being justified or explained (requirements or design).
- Secondly, use cases and the requirements components related to them – goals and scenarios – have some explanatory power [3]. A scenario / use case describes what people do, and each step has the justification both that it enables the next step to take place, and that it leads to achieving a goal (the title of the use case). Unfortunately, these useful data structures only cover part of the territory of explaining and justifying. In particular, they do not cover any kind of reasoning about the context of a project, namely the environment.

Do projects need to document and visualize rationale? The reasons for including a requirement in a specification, or for taking a design decision, define the purpose of that element, or sometimes of the entire project. Those reasons encapsulate the project's knowledge of

- the risks they knew they were taking, and crucially
- the conditions under which the decisions they made would hold, and when they would be wrong.

These are central to the success of any project. Indeed, much of the work in starting a new project consists in re-identifying these basic foundations: for often, the required knowledge already exists somewhere, but cannot be reused because it is too poorly documented.

This paper therefore suggests a simple way of describing and visualizing project rationale. Its main purposes are to justify requirements and design decisions, and to reduce the risk and cost associated with unexplained decisions. It may also assist in requirement and design reuse.

The rest of this paper is structured as follows.

Section 2 describes the proposed approach to rationale modelling.

Section 3 presents some examples of rationale model diagrams from a Transportation project.

Section 4 makes some observations on the effect of rationale modelling, based on the case study.

Section 5 compares the proposed approach with other ways of handling rationale.

2. Proposed Approach

This section describes the proposed approach and defines the main terms used.

2.1. Approach

Classical reasoning is based on "certain" facts or truths. But certainty is rare in industry. So, we can assert that classical reasoning is rarely useful for reasoning in industry.

Toulmin [4] was aware of this problem, and proposed a structure of "substantial" argumentation for practical use (Figure 1). A conclusion is broadly supported (but not logically entailed) by Facts and a Warrant, an argument that the conclusion holds given the Facts. The Warrant in turn is broadly supported by a Backing, which in turn may be a conclusion supported in the same way as the first one. A conclusion may be wrong; an argument tending to contradict it may be provided as a Rebuttal, which in its turn may be a conclusion with its own facts and warrants.

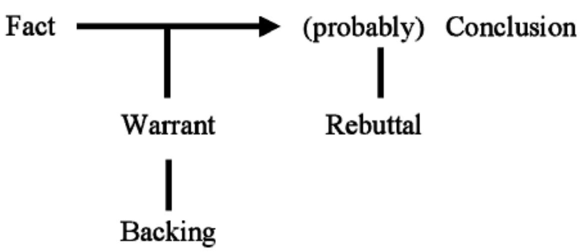


Figure 1 Toulmin Argumentation

However persuasive this is, it is quite complicated – it looks as if Toulmin argumentation demands 5 separate types of item.

But all the individual items of reasoning (whether they are initially labelled conclusion, fact, warrant, backing, or rebuttal) are

1) uncertain (not logical tautologies)
2) can play different roles in relation to other items of reasoning. For example, warrant w for conclusion c could itself be the conclusion c2 of another chain of reasoning, with warrant w2: ie, w and c2 are alternative labels for the same item. The same goes for backings, rebuttals, and arguably also for facts.

Therefore, Toulmin arguments can be modelled with just one type of item, "uncertain piece of argumentation". See the Case Study (section 3 below) for illustrations of how this works in practice.

Proposal 1: Let us call Toulmin argumentation items "Assumptions".

Proposal 2: Since Toulmin has shown that arguments can with benefit be represented as diagrams using arrows for chains of reasoning, let us draw arguments as chains of text boxes (for Assumptions) linked by labelled arrows (Warrant supporting optionally labelled +; Rebuttal weakening labelled –).

Assumptions can be wrong (ie mistaken), or can break (when the world changes). The intention here is to describe arguments, both for and against a proposed course of action, as objectively as possible. Different stakeholders [6] may well hold some combinations of the documented assumptions as subjective beliefs, but those are essentially inaccessible to the project.

Dewar [5] proposes the use of Signposts to trigger re-planning when important assumptions break. A Signpost can be seen as a corrective to the basic weakness of "substantial" argumentation compared to classical reasoning: it can be or become wrong. By monitoring conditions in the world that could cause assumptions to break, Signposts reconnect rationale to reality. The combination does not guarantee correctness, but in the absence of mathematical certainty, it is the next best thing.

2.2. Definitions

Based on the treatment of rationale just described, we can define a set of suitable terms with the following meanings. Entries in **Boldface** are defined terms. Entries in ***italics*** are (also) relationships.

Term	Definition
Assumption	A piece of "**substantial**" argumentation that people could take to be true: valid in the sense that it has some persuasive force
Goal	Something that somebody wants
Fact	An **Assumption** we believe to be very certainly true (such as that somebody has a specific **Goal**)
Conclusion	An **Assumption** that is supported by other Assumptions in a model
Design Decision	A choice affecting the design of a product that is supported by other **Assumptions** in a model
Signpost	An indicator that a project or business needs to monitor the world for the stated signs that an **Assumption** may be about to break
Backing	An **Assumption** that ***supports*** another Assumption (a **Warrant** or a **Rebuttal**) by providing evidence for it
Warrant	An **Assumption** that ***supports*** another Assumption by arguing in its favour
Rebuttal	An **Assumption** that ***weakens*** another Assumption by arguing against it
Substantial	(in Toulmin's sense), relating honestly but possibly mistakenly to things in the world (as opposed to a logical platitude which is certainly true)

supports	(relationship) indicating that the source **Assumption** increases belief in the target Assumption; can be written → + (the + sign is optional)
weakens	(relationship) indicating that the source **Assumption** decreases belief in the target Assumption; can be written → –
conflicts with	(relationship) a bidirectional ***weakens*** relationship between two **Assumptions**; can be written ↔ –

The key point is that a Toulmin rationale can be constructed using only Assumptions and relationships.

This can be supplemented with Signposts to tie a project's rationale to the state of the outside world.

It may also be helpful in some cases to show stakeholders' Goals directly (rather than somewhat artificially translating these into Assumptions that the goals hold), thus tying the rationale into other requirements engineering models used on a project, such as Stakeholder analyses [6] and Goal models.

3. Case Study: Rationale for a Transportation Project

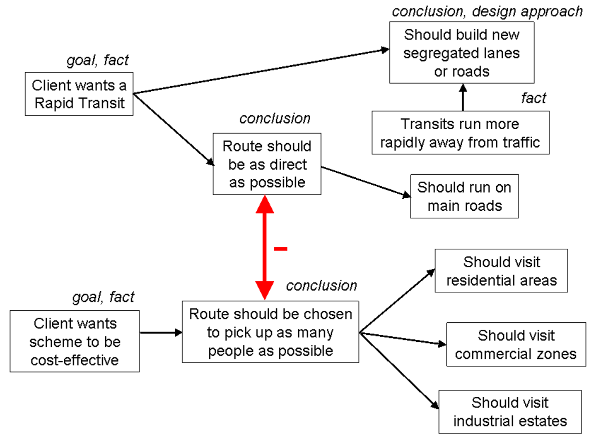
This section relates to a project in a major transport agency which is planning a Rapid Transit route to help regenerate a depressed area of a city.

The major challenge is not design but the selection of a workable route. Design is well covered in standards and manuals, eg [7], but almost anywhere that a route might run, there are difficulties. Opposition from powerful stakeholders [6] and legal obstacles can be expected if a route runs through the grounds of a school, a historic building or attractive townscape, a protected area of public open space, a nature reserve, a street already crowded with traffic, or the parking spaces on which retail businesses depend. Stakeholders including householders, businesses and local governments may be in favour if they feel they will benefit, or opposed if not. Further difficulties arise from conflicts with other services, if water and gas pipes and pumping stations, or electrical cables, pylons or switchgear need to be moved. Transportation has to compete for space in a crowded city.

In addition, there is a strict regulatory framework that demands fair evaluation of transport options on a range of criteria including the environment, value for money, safety, and effectiveness [8]. Proposals are subject to lengthy and costly scrutiny in a process that can easily lead to the failure of worthwhile schemes.

Under these conditions, it is essential that transport schemes are not merely right but seen to be so. Unworkable route options, for example, must not simply be rejected: the reasons for dropping them must be explained carefully and convincingly. The rationale for each decision must be recorded and if need be defended.

A transport project thus forms an effective testbed for rationale modelling. Goal conflicts are frequent, and the search for trade-offs to resolve such conflicts as well as possible (technically called 'satisficing' after Simon [9], but known as optioneering in industry) is one of the dominant requirement engineering activities on transport projects, as Alexander [10] explains.



A typical conflict is illustrated in Figure 2. Here, the client has two principal goals for a new transit route, to be operated with either articulated buses or trams. The route is to be a modern Rapid Transit, to connect other parts of the city's transport network, and probably also (a political goal) to show the city in a good light. The transit is however also to be cost-effective; indeed, the UK's rules for appraising competing route options demand that costs and benefits be assessed [8].

Figure 2 Analysis of a Requirements Conflict (Whether a Transit Route Should be Fast or Not)

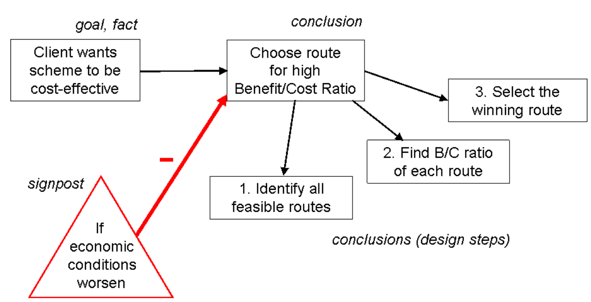


Figure 3 Analysis of a Method (Optioneering for Cost-Effectiveness)

Figure 3 illustrates the use of a rationale model to describe a process that may involve re-planning. It defines the conventional "optioneering" method of finding the best route for a transport scheme, with one addition. Given the rules demanding cost-effectiveness, a careful study is carried out with the purpose of finding the route with the highest Benefit/Cost ratio. This involves identifying all feasible routes – if a practicable route is not considered, a challenge might be mounted at public inquiry; each route is analysed for its costs and benefits, and a winner is selected accordingly. We may note in passing that not all impacts can be quantified or put into financial terms [10].

What the conventional optioneering process does not state is that the process itself is subject to the vagaries of events in the world outside, notably economics and politics. Figure 3 shows a Dewar-style 'signpost' which indicates an event in the world that the project must monitor. If the event occurs, it has a strong negative impact on the project. The appropriate response is to re-evaluate whether the proposed transport scheme remains viable under the changed conditions. The signpost adds resilience to the conventional process.

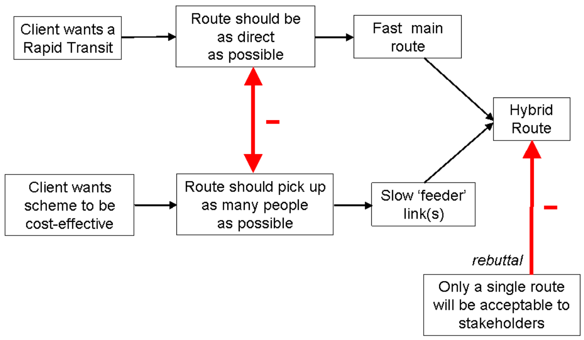


Figure 4 Resolving a Conflict (Reasons for Choosing a Hybrid Route)

Figure 4 illustrates a possible resolution to the conflict described in Figure 2. Rather than assuming (tacitly) that a single route must be chosen, the transit is envisaged as a fast main route (direct from A to B), fed with additional passengers by new links which may run through new housing developments, commercial centres and industrial estates. In this way the scheme can be both fast and cost-effective, though the business case's benefit/cost analysis now has to combine the costs and benefits of both main and feeder routes.

However, that approach will not work ("rebuttal") if stakeholders will only understand and accept a single clear route. In practice, therefore, the route will probably have to achieve a satisfactory compromise between directness and serving as many people as possible by running partly on main roads and partly through residential and industrial/commercial areas.

4. Observations

Multiple Roles Per Item

Figure 2 illustrates how individual items in a rationale model can play multiple roles (labelled in italics). An item can be the conclusion of one line of reasoning, the warrant for another, and the rebuttal for a third. For instance, the box "Route should be as direct as possible" is

- a *conclusion* with respect to the incoming goal/fact that supports it;
- a *warrant* with respect to the conclusion/design approach that derives from it;
- a *rebuttal* with respect to the conclusion that it is in conflict with.

Hence, attempting to create a rationale modelling approach that treats items as having fixed types, drawn as different shapes and symbols, etc, according to their roles in argumentation, is misguided. Treating all items as assumptions (with varying degrees of certainty) resolves the problem. A diagram can, as illustrated here, provide multiple labels where this is helpful. A tool could provide a switch to show or hide labels.

Signposting

Figure 3 shows how a signpost can be used to monitor events in the world. A signpost always forces a rethink, ie it explores a possible weakening of an assumption. It seems natural to diagram this with a negative arrow.

A signpost is a warning that a project needs to 'come up a level' from the details of its own procedures and timetable to observe the outside world. It can be seen as a meta-level symbol, showing that it is not safe to treat a business process such as optioneering as an isolated activity: the roof may fall in; the world may intrude.

Overlap with Goal Modelling

The two input 'facts' on the left-hand side of Figures 2 and 4 both represent goals, so an overlap exists between goal and rationale modelling. If we define a fact as a soundly-based assumption (unlikely to change), then a goal can be treated as a fact of the form *"Stakeholder S has the Goal G"*. If we didn't know exactly who owned a goal, we'd be left with the naked fact *"Goal G exists"*. Assumptions of this kind belong primarily in the goal modelling domain, and should ideally be used only as inputs in a rationale model, with a cross-reference to their source *"See Goals in section X"*.

Other assumptions, such as the conclusions in Figure 2, are more or less disputable. There is perhaps a spectrum of certainty in assumptions, running from quite dependable facts through to quite tentative warrants and conclusions.

While, therefore, a goal modeller can claim *"oh, I could put all that into a goal model"*, he's missing the point. We exactly do *not* know if making the transit route as direct as possible should be a project goal: that is an assumption we need to challenge and clarify. In the case of the transit project, the rationale needs to be documented and agreed on, *before* we can safely say *"this is an agreed goal of this project"*.

Conversely, when goals, design decisions etc are not in dispute, there may be no need for a rationale model: except that goals may be founded on unstated assumptions, which may be mistaken or which may break, undermining the project. The tacit assumption *"there must be a single route from A to B"* is an example of a possibly unnecessary constraint on a project.

Grounds for Building a Rationale Model

There are several practical grounds for building a rationale model:

1. when goals or other decisions conflict, and need to be resolved by optioneering;
2. when stakeholders dispute the need for a scheme, or object to details of it;
3. when unstated assumptions need to be explored. Since this is hard to predict, this may mean "on every project", in some degree;
4. when a proposed solution must be justified by a contractor to his client;
5. when decisions must be justified to a regulator, as with
   - a business case, as with a transport scheme (to the public inquiry inspector, and ultimately to a government minister)
   - a safety case, as in aerospace, railway, or nuclear power (to the aviation authorities, the safety inspectorate, etc)
6. when requirements and design will be revisited, as with reuse of features in a product line.

Perhaps this wealth of possible grounds suggests that many more projects should be capturing design rationale than currently are doing so.

Resolving Goal Conflicts

Figure 4 shows how simply and naturally a rationale model can display a proposed resolution to a goal conflict. The two goals that led to the conflict are shown to be able to support a hybrid route. A resolution of this kind is a technological fix, ie the conflict was assumed to exist because of the limited technologies perceived to be available. Progress or increased awareness can then resolve the conflict. This is another take on Toulmin's "substantial" reasoning: conclusions ("we have a conflict") are revisable in the light of fresh evidence. True logical conflicts are not revisable, but they are perhaps not as common as people think.

5. Comparisons

Rationale modelling, along with related aspects of project engineering like prioritisation and justification of requirements and design decisions, has long been somewhat neglected in general project practice, even if it has received some academic attention, eg by Kirschner, Buckingham Shum, Dutoit and others [11, 12, 16].

Comparison with Safety Case Rationale

Argumentation is routinely deployed in constructing safety cases in the aerospace, railway and nuclear industries, eg using Claims-Arguments-Evidence (CAE) [13] and Goal Structuring Notation (GSN) [14]. However, it has hardly spread outside that realm, so it is disappointing that [11] overlooks the safety domain. The industrial perspective of the current paper may form a small counterweight to that unbalanced contribution.

Perhaps the limited spread of rationale modelling from the safety domain is because of the perceived cost and complexity of learning and using the notations, and the tools that support them. That complexity is undesirable in general industrial use, where few notations beyond the flowchart and the project plan are really well accepted.

<table>
<tr><th>Toulmin</th><th>Alexander</th><th>CAE</th><th>GSN</th></tr>
<tr><td>Conclusion</td><td rowspan="3">Assumption</td><td>Claim</td><td>Goal</td></tr>
<tr><td>Warrant, Rebuttal, Backing</td><td>Argument</td><td>Goal, Argument</td></tr>
<tr><td>Fact</td><td>Evidence</td><td>Solution, Context</td></tr>
<tr><td>–</td><td>Signpost</td><td>–</td><td>–</td></tr>
</table>

Table 1: The Mapping Between Different Rationale Modelling Constructs

This is not the place for an academic analysis of the merits and structure of alternative rationale modelling notations. However Table 1 shows the mapping of constructs between the four notations mentioned here. It is apparent that:

- there is no agreement on names for any of the constructs, nor on how many are needed. The notation presented here is intentionally minimal; it is recognised that "Assumptions" can have varying degrees of certainty attached, though even a "racing certainty" does not have a truth-value of 1.
- CAE has the same problem as Toulmin, on which it is ultimately based: claims, arguments and evidence are not really fixed: what is a claim in one place is an argument in another.
- GSN is less vulnerable to the multi-role problem, since "goal" can play different roles; but despite that useful simplification, GSN not CAE is the more complex graphical notation.

Comparison with Textual Rationale

Rationale is most often expressed as text. For comparison, here is the argumentation of Figure 4, written in the style of a typical transportation industry optioneering report.

> *"On journey time reduction, it can be seen that the Main Route (A) achieves a greater JTR (11 minutes) than either the Estates Route (B, 4 minutes) or the Hybrid Route (C, 7 minutes). Therefore on this criterion, route A has a significant advantage.*
>
> *On patronage, in contrast, routes B and C have an advantage over route A, due to their visiting more residential areas as well as more workplaces and commercial centres. It is difficult to quantify this benefit, as without the route in place there are relatively low flows today between these areas. Conversely, route A may attract new flows from*

outside the study area by offering a rapid link from north to south.

Route C would therefore seem to be favoured over both A and B, on balance between these two criteria. However, project opinion, confirmed by consultation, is that the offering to stakeholders must be a single route, excluding route C from consideration."

The textual account is discursive; it is quite informal, and not hard to follow once the industry jargon (eg JTR, flow) has been acquired. Without the visual structure of Figure 4, the reader must pay quite close attention to the text to build an understanding of the underlying argument.

Steven Pinker [15] argues that the brain models reasoning by simulating it with "naïve physics": force A (the warrant) overcomes resistance B (rebuttal). Toulmin argumentation is evidently close enough to naïve physics to feel like a natural way to express reasoning. A Toulmin-based graphical notation provides a sharper view of rationale than a text does, by showing directly the parts of an argument and their connections.

6. Conclusions

Merits of a Simple Notation

Academic attention has focussed either on pure argumentation, eg [4, 11, 16], or on pure safety case construction, eg [13, 14]. But there is a gap between these for ordinary development project decision-making.

This paper suggests that there is a place for a far simpler graphical notation than say GSN, that compactly expresses the rationale for a project decision. It presents a robust way of representing rationale for industry, based on the thinking of Toulmin and Dewar. The notation consists essentially of just two symbols – a box and an arrow, optionally labelled with types, and optionally supplemented with Dewar signposts. The resulting diagrams are clear and uncluttered – indeed, they could hardly be plainer.

In practice, transport projects have made widely varying uses of rationale models. For example, one project diagrammed traceability between its assessment criteria and its objectives, showing support and possible conflict. Another project used rationale diagrams informally when assessing alternative design options.

Uses of Rationale Models

Rationale Models (RM) of the type described here may be useful for several purposes:

- Figures 2 and 4 suggest that RM may be helpful in clarifying and resolving requirements and design conflicts. A rationale model would form the core representation of a conflict, and would be worked on and reasoned from in conflict resolution process, involving fact-finding, workshops and negotiation.
- Figure 3 suggests that RM may also be helpful in defining and justifying business processes, and especially in making them more resilient.
- Explaining the reasons for requirement and design decisions helps to determine relative priorities, especially when these cannot readily be quantified or costed.

Limits to Rationale Modelling

Rationale models are not needed everywhere. Even on projects where some decisions deserve the full treatment, other decisions may not. Rationale is worth visualizing when a decision could be contested or otherwise revisited, and the reasons for it could easily be forgotten. Industry is a practical place; it values models only for the service they can offer, not for their cleverness.

Acknowledgements

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