ENGINEERING DESIGN RESOURCE PLANNING: A CASE STUDY IN IDENTIFYING RESOURCE FORECASTING OPPORTUNITIES IN RESEARCH PROJECT PLANNING

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Abstract

Resource forecasting is a key element to project planning, this is particularly true for research and design. Due to uncertainties inherent in such fields, resource demand forecasting is a specific challenge. This presents an opportunity for mapping out research planning processes, identifying opportunities for resource forecasting methods. Building on research conducted at an engineering research centre, this study explores the two types of engineering research projects (Commercial and Public Research & Development). Individual projects can utilise multiple engineering teams within the research centre and both project types have their own distinct planning process. This study outlines these existing project planning processes, the resource planning stages within the process, what informs the resource planning and what opportunities are present for improvement of these processes.

Keywords: Process modelling, Project management, Uncertainty, Project planning, Resource forecasting

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Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 2: Design Processes | Design Organisation and Management, Vancouver, Canada, 21.-25.08.2017.

1 INTRODUCTION

The planning process, and the constituent resource planning activities, are critical to the success of any design project. However, due to its inherent nature, the outcome of design is unknown, and therefore design project resource forecasting casting is intrinsically uncertain, increasing the likelihood of inaccuracy. The same is true for engineering research projects, where the outcomes of research activities, experimentation, etc. are not known at the outset, or indeed during, a project. Overestimating resources will lead to overspending and waste, underestimating leads to issues such as project delay (Elonen and Artto, 2003). The aim of this study is to map out the project planning processes for engineering research to identify opportunities within the process to introduce the resource forecasting method called Structured Perception Modelling (Hird et al., 2016). Due to the inherent level of uncertainty in both research and design activities, one can consider engineering research as an analogue for design projects, therefore this study looks to identify (where available) the lessons that can be drawn that are transferrable between research and design. This case study looks at an engineering research centre with close ties to a university and partnerships with industry; here on referred to as Research Centre A. Research Centre A conducts two different research project types: Commercial projects; and Public Research and Development (PRD) projects. Each project type has a different project planning process, neither of which has been fully prescribed by the Research Centre A's management, but have been developed organically over time. This paper will: describe the project planning processes, offering IDEFØ diagrams (due to space limitations, the full suite of diagrams has not been included in this article but can be found online: http://dx.doi.org/10.15129/18ed2295-5b9b-4881-9580-8b3ac2fd1940) as a structure for Research Centre A staff, other research engineers, design engineers and designers to follow when planning their own projects, detailing the stages of the planning processes, identifying possible steps which could be improved by a resource forecasting model.

2 PLANNING DESIGN PROJECTS AND RESEARCH PROJECTS & RESOURCE PLANNING REVIEW

2.1 Planning Design Projects

Developing a detailed and clear plan is the first stage of the Design project process (Jack, 2013). However, the design process is inherently uncertain (Pich et al., 2002) caused by inter-dependent procedures and the iterative design activities intrinsic to the process (Eppinger et al., 1994) (Whitney, 1990), and unexpected changes from the project outset (Xin Chen et al., 2015) (Wynn et al., 2014). Although uncertainty can be reduced systematically, through organisation, integration and analysis of information (Danilovic and Browning, 2007) and easier to control with experience (Jack, 2013), the problems associated with design project planning are fundamentally wicked (Rittel and Webber, 1973). Accurately predicted appropriate resources are crucial to a design project's length and cost (Xin Chen et al., 2015) and if done poorly, can be a "killer" for cost benefit analysis (Jack, 2013). Therefore, the introduction of resource forecasting into the design planning process can be considered a means to address this critical requirement.

2.2 Planning Research Projects

Effective project planning is the key component of project management, with Dvir et al drawing a positive correlation between project planning activities and project success (Dvir et al., 2003). However, project planning is not universally regarded as beneficial. Bart suggests that over-planning can reduce creativity in R&D Projects (Bart, 1993). Initial planning is often flawed due to the large number of interacting variables, therefore Chatzoglou and Macaulay suggest that the planning process should be iterative (Chatzoglou and Macaulay, 1996). Furthermore, Andersen suggests that activity planning for projects can be inaccurate as latter activities are dependent on the outcome if preceding activities (Andersen, 1996), and therefore proposes a result-based planning (milestone planning) method. Some approaches have been developed to improve upon, or augment, the planning process, for example; at a strategic level, Chen and Bullington outline a structured process for planning the research program of a university department based on the Quality Function Deployment (QFD) (Chen and Bullington, 1993). At a tactical level, research planning methods include the use of tools, such as Research planning diagrams (RPD) (Davies, 1970) and Graphical Evaluation & Review Technique (GERT) (Pritsker, 1966).

2.3 Planning Project Resources

Project management is a common method for maintaining a competitive edge in business (Grant and Pennypacker, 2006), therefore resource planning, a barrier to effective project management (Pearson, 1990), is a challenge to be overcome. Poor resource planning can lead to underestimations (Elonen and Artto, 2003) increasing lead times and reducing competitiveness. A lack of resources and inadequate planning and estimating of said resources are key restrictions to effective project management (Pearson, 1990). The planning of project resources such as consumables including time, money, energy, etc. (Browning et al., 2006) and in particular scarce resources such as equipment and specialists (Kavadias, Stylianos, Loch, 2004) are essential to research project planning processes within multi-project environments (Adler, 1994) (Pinto and Slevin, 1987). Therefore, for effective planning of resources to occur, accurate resource forecasting is essential (Hird et al., 2016).
The planning of projects is therefore critical to their success. However, as design and research are inherently uncertain, the critical practice of project planning has particular challenges. Nowhere is this truer than in resource planning. Inaccurate resource planning can cost designers and researchers alike time, money and resources. Design and research both see their projects plan iterate, with resource demands change. Therefore, accurate forecasting of resources would minimise the incurred cost of iteration and inaccurate planning.

3 METHOD

This study will map the planning processes of Research Centre A, identifying opportunities for the introduction of resource forecasting methods and other transferable lessons from engineering research projects to design projects. The Research Centre A follows the ISO9001 Quality Management System (QMS) for all projects, however their specific project planning processes are not fully formalised and documented, The Research Centre A's "Business Development Procedure" document provides a procedural overview, identifying roles and responsibilities, etc. it specifically outlines a 6-step process and 11 step process for commercial project planning and PRD project planning respectively. Therefore, to achieve a detailed understanding of the planning process, detailed IDEFØ models have been produced in conjunction with various members of the Research Centre A's Commercial Business Development team, PRD Business Development team Programme Management team. Both project types were modelled with an iterative process, using a semi-structured interview approach. Multiple initial models were developed in conjunction with Senior Business Development Managers for Commercial and PRD projects at the Research Centre A. Once refined and completed, these IDEFØ models were then evaluated by other members of the Business Development team and Programme Management team members in groups to verify an accurate description of each process, eliminating perspective biases of individuals.

3.1 Integration DEFinition (IDEFØ)

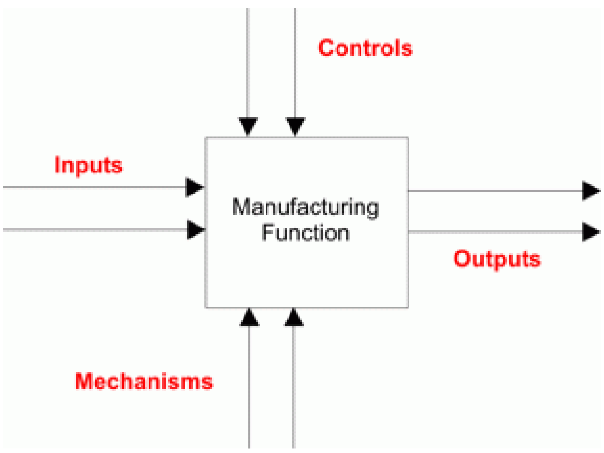

Figure 1. IDEFØ Box and Arrow Graphic (Knowledge Based Systems Inc., n.d.)

The Integrated DEFinition (IDEF) modelling methodologies were developed for use in the US aerospace industry in the 1970s. By the mid-1970s IDEF methodologies' diverse range of uses saw them become well regarded in contrast to other modelling, particularly IDEF0 (Marca and McGowan, 1987). IDEFØ is an organization or system modelling method, describing decisions, actions, and activities, and is derived from Structured Analysis and Design Technique (SADT) (Knowledge Based Systems, n.d.). IDEFØ models have been selected for this study as they can describe a process by activity or function, identifying inputs and outputs (typically information), controls (personnel, documents, etc.) and mechanisms (terms & conditions, templates, etc.) outlined in Figure 1.

4 PROJECT RESEARCH TYPES

Two types of projects are undertaken at the Research Centre A: Commercial and Public Research & Development (PRD). Commercial projects are initiated from external bodies (companies, other institutions, etc.). They are typically conducted at short notice with the external body looking to "have a problem fixed" as quickly as possible. This is the equivalent to a commercial design project for a design consultancy, with a commercial client providing brief, funding, etc. Public Research & Development (PRD) projects are funded (or partially funded) by regional, national, European and international bodies. Such projects are typically arranged with other engineering firms, SME's and academic institutions. This is the equivalent to an individual client, where they will require financial support to commission design work. Each heading of sections 4.1 and 4.2 are named after the corresponding section of the relevant IDEFØ model, found online at http://dx.doi.org/10.15129/18ed2295-5b9b-4881-9580-8b3ac2fd1940.

4.1 Commercial Project Planning Process

Five phases of a commercial project planning process have been identified in Table 1 and Figure 2:

Table 1. Commercial Project Planning Process Phases

Commercial Project Planning Process Stage	IDEFØ Model Name
Generate Statement of Requirements	RCA_COM_03
Assemble a Project Team	RCA_COM_04 - 06
Produce Project Documents	RCA_COM_07
Obtain Approval from Customer	RCA_COM_08
Finalise Project Planning & Project Start	RCA_COM_09

This is unlike the six-stage process outlined in the Research Centre A's "Business Development Procedure which describes the process as steps within a "Plan, Do, Study, Act" (with two parts to the "study" and "act" process)

4.1.1 Generate customer work & Statement of Requirements

Each commercial research project will start with:

- An external enquiry: An enquiry from third party companies.
- An internal enquiry: An enquiry from within the university, RCA or RCA partners.
- A Change in business direction: Where the RCA and partners change their business direction, amending ISO9001 Quality Management System (QMS) QP01 document.

Enquiries are checked against the RCA's scope (their area of expertise, similar to that of a design agency's design field (i.e. medical devices, packaging, heavy industry, etc.)), approved or rejected and a statement of requirements (SOR) is created, capturing the customer expectations, containing "everything you need to know [to conduct the research project] that is acceptable to the customer, and no more." [23]. The SOR is similar to that of a design brief in its details and purpose.

4.1.2 Assemble a Project Team

The assembly of a project team comprises of three phases:

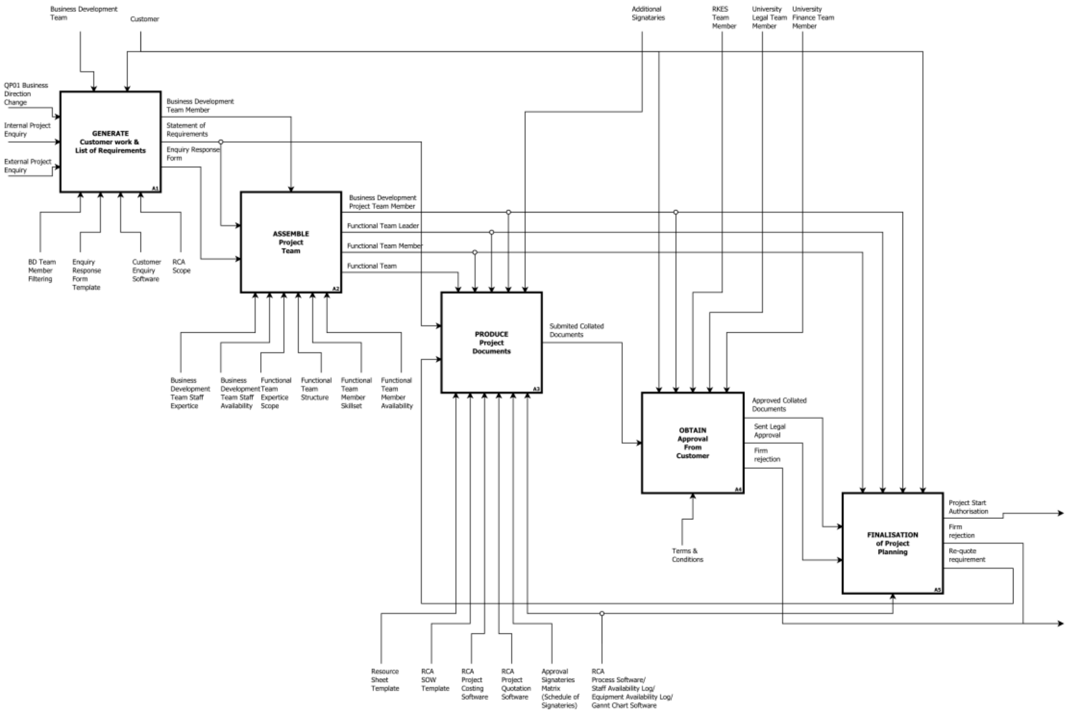

Figure 2. RCA Commercial Project Planning Process IDEFØ

4.1.3 Confirm Business Development team member suitability

The Business Development team will assign the most suitable member to the project. This assignment will be based on team members experience, skillset and availability. The chosen team member will assume the role of Business Development Project Team Member for the project.

4.1.4 Identify and appoint Engineering Team(s) & Leadership

The engineering teams required to conduct the research are identified, based on the Statement of Requirements. Where more than one team is needed, a primary team is identified based on the division of expected workload, and the team leader is appointed Engineering Team Leader. During this phase, a member of the Program Management team will be assigned as the Program Management Team Member. Although the Program Management Team Member's role is ancillary during this phase of project planning, their influence gradually increases during the course of the planning process, until the planning finalisation phase, when they have assumed full control.

4.1.5 Identify and appoint Engineering Team member

The Engineering Team Leader will identify the most suitable member of their team to undertake the research. This will be based on the engineer's relevant experience and skillset. Engineering Team Member selection is also influenced by engineers' availability (workload), therefore the selected engineer will be in the first instance available, then qualified.

4.1.6 Produce Project Documents

Project planning documentation are produced by the Engineering Team Member and Business Development Team member, with the workload outlined in Table 2. During this phase, the Program Management Team Member will provide support to the Engineering Team Member and the Business Development Team member.

Table 2. RCA Project Planning Documents

Engineering Team Member	Statement of Work, Work Breakdown, Gantt Chart, Resource Sheet
Business Development Team member	Project Costing, Project Quotation

The Engineering Team Member's planning documents are used to describe project deliverables and the activities necessary to produce them, as well as forecasting the resources required to undertake the project. These documents are then transferred to the Business Development Project Team Member and inform the costing of the project, which, in turn, inform the project quotation. All project planning documents are then submitted for internal approval by additional signatories (typically the Executive team at the RCA) based on the overall cost of the project, and is identified by a schedule of signatories. Once signed off, the quotation is submitted to the customer.

4.1.7 Obtain Approval from Customer

An approval from the customer for a submitted quotation will lead to a Purchase Order (PO) being raised and returned to the Business Development team. However, prior to any PO being raised, the customer and their legal representation will enter discussions with the university's legal team, Research Services team and financial team to negotiate the terms and conditions of the project.

4.1.8 Finalise Project Planning & Project Start

Once legal and financial agreements, such as non-disclosure agreements, schedule of payments, etc. have been made and a PO is received by the Business Development Team Leader, the project is then handed off to the Engineering Team and the Program Management team. The original Gantt chart, Work Breakdown and Resource Sheet are then checked to see if they are still valid. All planning included with quotations produced by the RCA are valid for 28 days, and although can be extended, may lapse if other projects start during the approval phase. If the approval process takes longer than 28 days, the planning documents may need to be updated in order to reflect resource availability. In these cases, the updated planning will be submitted to the customer for final approval, as the delivery date of the project will likely be later than initially advised. Upon receiving customer approval of the updated project timescales, authorisation will be given to the engineering team to commence work on the project.

4.2 Collaborative Research and Development Project Planning Process

PRD Project Planning has four multi-stage phases prior to work start, with an additional repeated review phase conducted regularly during research as shown in Table 3 and Figure 3.

Table 3. Public Research & Development Project Planning Process Phases

Project Planning Process Stage	**IDEFØ Model Name**
Developing a bid for funding	RCA_PRD_2 - 9
Approving Bid by funder	RCA_PRD_10
Finalise Project Planning	RCA_PRD_11 - 12
Confirming Project Funding	RCA_PRD_13
Monitoring Project Progress	RCA_PRD_2

4.2.1 Developing a bid for funding

Similar to commercial projects at the RCA, an initial enquiry from an external third party who has a clear aim for a research project. This is the equivalent to building a business case for a business loan, venture capital funding, etc. This external enquiry prompts the start of a PRD project and comprises of five stages:

4.2.1.1 Define project scope

Identifying and appointing other potential businesses and institutions that could participate with the research project, outlining the RCA's involvement within the project and producing a budget breakdown of what funding is required and which stakeholders are responsible.

4.2.1.2 Appoint Business Development Team Member

Identifying and appointing the most suitable, available member of the PRD Business Development team.

4.2.1.3 Select Engineering Team(s)

Identifying and appointing the engineering team(s) required for the project, selecting the most suitable team as the primary engineering team, if required; and appointing the Engineering Team Leader.

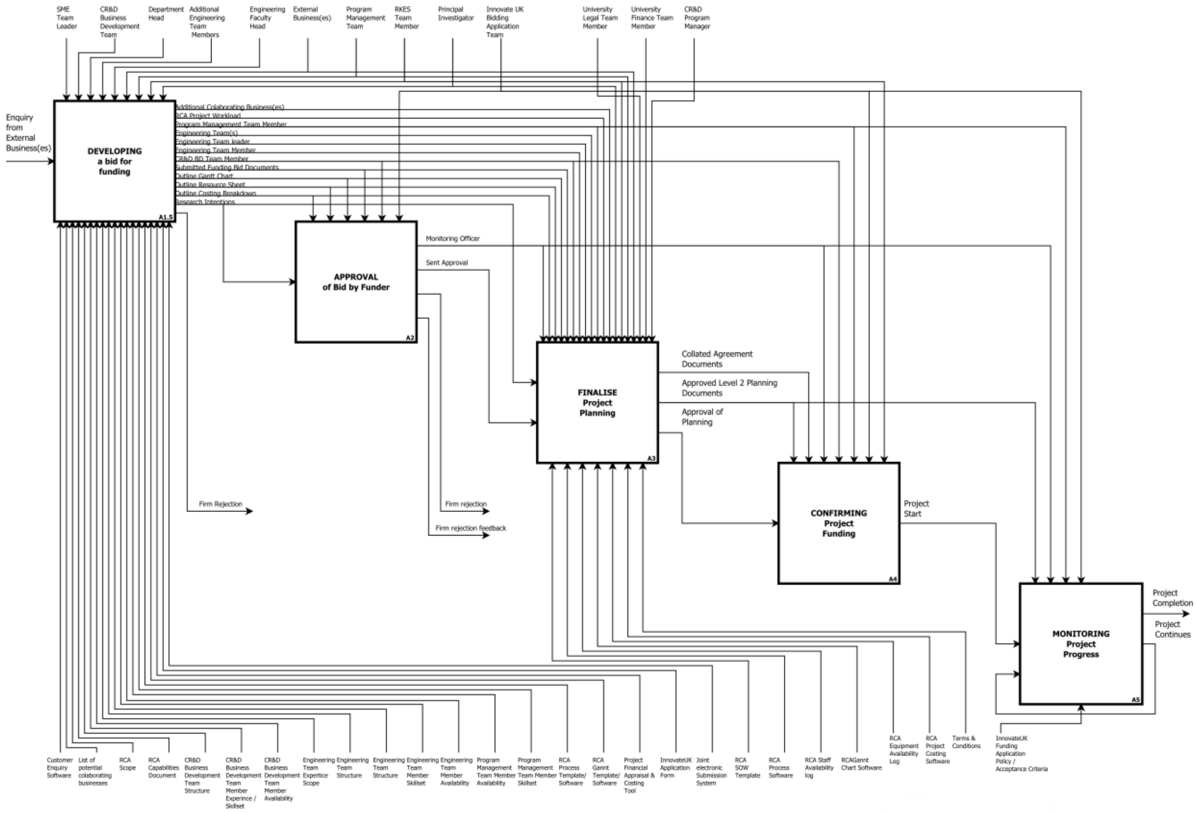

Figure 3. RCA PRD Project Planning Process IDEFØ

4.2.1.4 Create a bid team

Identifying and appointing a member of the primary engineering team as the Engineering Team member. This will be based on the engineer's relevant experience and skillset. Engineering Team Member selection is also influenced by engineers' availability (workload), therefore the selected engineer will be in the first instance available, then qualified.

4.2.1.5 Produce Project Planning Documentation

Concurrently creating documents including an outline resource sheet, outline Gantt chart and costing breakdown. From which further actions are taken:

- Discuss Go/No-Go of project
  - A decision point for the project team after checking that agreements that have been made and arranged plans are suitable, allowing the bid team to amend any documents if required.
- Complete bid application forms
  - Each funding bid requires the completion of application forms.
- Submit for approval
  - Bid documents will be checked by the RCA's Principal Investigator, the Research Services team and departmental approval.
- Submit bid
  - Sending all completed documentation to the funding body for approval.

4.2.2 Approving bid by funder

The initial approval process sees the funding body receive a completed bid for funding and discussions with the Business Development Project Team Member may be required. Once a bid is successful, the funding organisation will assign a Monitoring Officer to act as a liaison with the bid team.

4.2.3 Finalising project planning

The finalisation of project planning has two stages: Processing of Contracts & Agreements and Producing of Level-2 planning documents.

4.2.3.1 Processing of Contracts & Agreements

Upon approval, bid documents will be submitted to the university's legal team to produce and approve contracts, IP agreements, collaboration agreements and a financial burdens breakdown.

4.2.3.2 Producing of Level-2 Planning Documents

Level-2 planning documents are similar to the planning documents of the commercial process. The SOW, WB, Gantt chart and resource sheet all created by the Engineering Team Member and overseen by the Engineering Team Leader and Program Management Team Member. Level-2 documents are submitted for pre-approval with the Principal Investigator.

4.2.4 Confirming Funding

The funders will receive all Contracts & Agreements and Level-2 documents and once approved, will issue an Approval Letter, confirming funding (amounts and payment schedules). Upon receipt of the Approval Letter, the Research Services team will setup accounts, budget codes, etc. and at project start, control is assumed by the Program Management Team Member.

4.2.5 Monitoring project progress

PRD projects are reviewed quarterly to ensure that project progress and budget spend are as planned. The funder will check progress against their acceptance criteria.

5 DISCUSSION

This section will discuss the impact particular stages of the planning processes have on their outcome. Such stages have been identified as potential points for the introduction of resource forecasting models.

5.1 Commercial Projects: Project start delays

Project quotations from the RCA are valid for 28 days. However, project starts can be delayed because of prolonged customer approval (approving work and raising a PO) and legal agreements. Although these agreements can be started once the Statement of Requirements has be generated, the process can take many months, based on a number of factors, including project complexity and novelty and whether this is the first project undertaken by the RCA for the customer. Delayed approvals lead to the extension of the finalisation phase to check availability and reallocate resources, produce a new Gantt chart, etc. In lieu of overcoming causes of delay, a possible method for streamlining, and therefore expediting the planning and potential re-planning stages could be the introduction of resource forecasting methods, such as Structured Perception Modelling (Hird et al., 2016).

5.2 Staff Availability vs. Experience

Both project types see the Engineering Team Leader select Engineering Team Members based on experience, skillset and availability. It is common for the most suitable engineer (based on experience and skillset) to be unavailable, based on workload, annual leave, etc. This causes the Engineering Team Leader to repeatedly identify the next most suitable engineer (based on experience and skillset) to then check their availability, recruiting the engineer who is most suitable by experience and skillset, and who is available for the tasks of the project. The resources for both commercial and PRD processes are planned by the assigned Engineering Team Member. It is the Engineering Team Member's experience and skillset that are the basis for their decision making. As each project may not be planned by the most suitable engineer (based on experience and knowledge), the introduction of resource forecasting methods, such as Structured Perception Modelling (Hird et al., 2016), would allow planners to reproduce the expert knowledge of the most suitable engineer accurately and quickly.

5.3 Feedback Mechanisms

Both project processes are, in the main, linear, with limited feedback between process sections. Feedback loops are only found in two areas. Simple feedback loops are seen during staff availability checks, such as those seen in documents RCA_COM_06 and RCA_PRD_07. Additional feedback loops are found in approval checks, such as those shown in documents: RCA_COM_07, RCA_COM_08, RCA_PRD_08, RCA_PRD_10, and RCA_PRD_13. (All IDEFØ models found at: http://dx.doi.org/10.15129/18ed2295-5b9b-4881-9580-8b3ac2fd1940). These feedback loops inform points of the processes described within the same section of IDEFØ model. Without higher level feedback loops (between sections) these processes are rigid and unadaptable. Future adaptations of these processes should seek to add feedback structures to improve their performance.

6 CONCLUSION

Research projects, like design projects, have inherent uncertainty. Therefore, findings from one field may inform and benefit the other. Although project planning processes may take different forms, exemplified by those of the commercial and PRD research projects at RCA, each are similar as they require, among other things, resource planning. In the project planning process, it is typical for resource predictions and allocation to change, requiring re-planning. Indeed, project re-planning is a part of the commercial and PRD project planning process at the RCA, caused by delayed customer approval in consumer projects, and the requirement for varying levels of plans (outline and level-2) in PRD projects. These are both opportunities for resource forecasting methods to be introduced to improve the process. Furthermore, the planning of both project types can be influenced by the unbalanced workloads of engineers, resulting in the most available engineer, rather than the most suitable engineer, planning the project tasks and estimating resources. This is an opportunity for a resource forecasting model, such as Structured Perception Modelling (Hird et al., 2016) which reproduces expert knowledge within areas of inherent uncertainty, to be introduced to reduce variance in the knowledge and experience based accuracy of future project planning. Furthermore, by objectively modelling the planning process, one is provided with a basis to begin benchmarking best practice and offer insight for project managers, engineers and designers and their own similar planning processes.

Future work would see the application of the method from this case study to other engineering research centres, so that direct comparisons can be made, and common practices can be identified. In addition, this method could be used within engineering design/design consultancy environments to gain further insight in the design project planning processes. From this, further comparisons can be drawn to the processes of engineering research and identify additional areas for the introduction of resource planning. Furthermore, research be conducted into alternative suitable resource forecasting methods and their introduction into these processes to evaluate their suitability and accuracy.

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