Analysing Process Models Quantitatively

Keith Phalp and Martin Shepperd
{kphalp, mshepper}@bournemouth.ac.uk
Empirical Software Engineering Research Group
Department of Computing
Bournemouth University
Talbot Campus, Fern Barrow
Poole, Dorset, BH12 5BB, UK

Abstract

Over the years, there has been much interest in modelling processes. Processes include those associated with the development of software and those business processes that make use of software systems. Recent research in Systems Engineering for Business Process Change[1] highlights the importance of modelling business processes in order to evolve and maintain the legacy systems that support those processes. Business processes are typically described with static (diagrammatic) models. This paper illustrates how quantitative techniques can facilitate analysis of such models. This is illustrated with reference to the process modelling notation Role Activity Diagrams (RADs). An example process, taken from an investigation of the bidding process of a large telecommunications systems supplier, is used to show how a quantitative approach can be used to highlight features in RADs that are useful to the process modeller. We show how simple measures reveal high levels of role coupling and discrepancies between different perspectives. Since the models are non-trivial — there are 101 roles and almost 300 activities — we argue that quantitative analysis can be a useful adjunct for the modeller.

Keywords: process modelling, measurement, Role Activity Diagrams (RADs), case study, process improvement

1. Introduction

Software developers are becoming increasingly aware of the need to model the business processes of their clients or customers [7]. This modelling is important because the software being developed should support those business processes, so an important prerequisite is to understand the business needs and context for the proposed system. In addition, the output from business modelling may also

[1] Systems Engineering for Business Process Change is a research programme funded by the UK Engineering and Physical Sciences Research Council.

be used within the software development process. For example, Yourdon notes how strategic (business) modelling, is used as an input to object-oriented analysis [12]. A further use of business models is within legacy systems. Here the client intends to make changes to a business process supported by an existing system or systems. It is suggested that by understanding the relationship between the business process and the supporting system, proposed changes can be more efficiently gauged and managed [9]. Consequently, a number of researchers have attempted to model both business processes and legacy systems, and construct mappings between them [10]. This mapping is then used in order to predict how changes to the business process affect the system and consequently support its evolution.

Software process modelling has been used in software engineering for a number of years in order to better understand, manage and control the development process [8]. The description of customer processes, however, presents software engineers with a new audience, requiring different approaches and the use of different notations and techniques. For example, if models are to be used in order to describe and validate business needs, then it is important that they be couched in terms that are meaningful to the customer. Hence, it is appropriate to use the kind of models that have been successful within business process re-engineering. (The choice of what kind of model to use is, of course, one that has fuelled a great deal of debate. A discussion of these issues, can be found in [7]).

Despite the existence of many formal process modelling notations, the majority of the business reengineering community use simple diagrammatic modelling techniques [4]. These techniques allow the modeller to discuss and validate process models with both users and owners of the process, many of whom are not prepared to invest their time in understanding more complex representations. Consequently, analysis of processes often consists solely of inspection of diagrams. Typically, this analysis will be guided by the application of heuristics, the experience of the modellers and their knowledge of the particular business domain [5]. Analysis can be time consuming and the conclusions are frequently heavily dependent upon the skill of the modeller.

This paper proposes that simple measures of process diagrams can be used to complement and guide expert analysis of process models. We believe that this may be of interest, particularly when the processes are complex or expert modellers are unavailable. To illustrate this idea, the paper uses the notation of Role Activity Diagrams (RADs) [6], which is described in the next section. RADs are an example of a behavioural approach to process modelling [2]. Note that the aim of this paper is to illustrate the utility of using a quantitative approach to aid the analysis of static business process models, not to promote RADs, nor the specific measures of RADs suggested. The paper also suggests how various published heuristics for evaluating processes, such as minimising role coupling [5], can be supported by associated simple quantitative analysis and outlines the various counts and measures that we utilise. Results from a case study follow. These results suggest that a simple quantitative approach can support the investigation of business processes and is complementary to the usual qualitative means of analysis.

2. An Overview of RADs

Any given representation scheme depicts some perspective or perspectives of the process at the expense of others. For example, the notation might show the activities and information flow within the business process or alternatively the roles, actions and interactions therein. Consequently, this will be reflected in the choice of measures to support analysis of the process model. For example, one would expect different heuristics and measures for data flow diagrams [11] as opposed to RADs. The modelling purpose is also highly relevant. We choose, by way of example, RADs as our notation and understanding and restructuring extant processes as the purpose. We believe, however, that this approach may be applicable to other notations and purposes and discuss this further in the conclusions.

RADs were originally developed for software process modelling [6]. The notation reflects the move away from the functional depiction of organisations, to the examination of the behaviour and interactions of individuals or groups [3]. RADs have had extensive use and exposure within the process modelling and re-engineering community. Miers [4] describes RADs as 'the most powerful method of representing the degrees of freedom, or limits of empowerment offered to workers within the business'. The underlying paradigm is that of conditional action and closely related to Petri net theory.

Figure 1 illustrates a RAD depicting a hypothetical process for a design project. A role (depicted as a rounded rectangle) groups activities together which might be carried out by a person, group or machine (an actor or an agent). There are three roles in this process model, namely Divisional Director, Project Manager and Designer. Actions (indicated by shaded squares), allow a role to move from its current state to a new state. Examples of actions in Figure 1 include "prepare a plan" and "choose a method". Roles act in parallel, and communicate and synchronise through interactions (shown as unshaded squares joined by a horizontal line). "Agree TOR for a project" is an example of such an interaction. Interactions are like shared events, in that all roles involved move from their current state to the next state as a result of the interaction. Some authors denote the 'driving' or initiating role of an interaction with a cross-hatched square - and this convention is followed within Figure 1. Hence, a divisional director drives the interaction to agree a terms of reference with a project manager.

Vertical state lines joining actions and interactions show the thread of control within a role. A role has constructs to depict concurrent or parallel behaviour, known as part-refinement, shown by a point-up triangle. Choice, known as case-refinement, is shown by a point-down triangle.

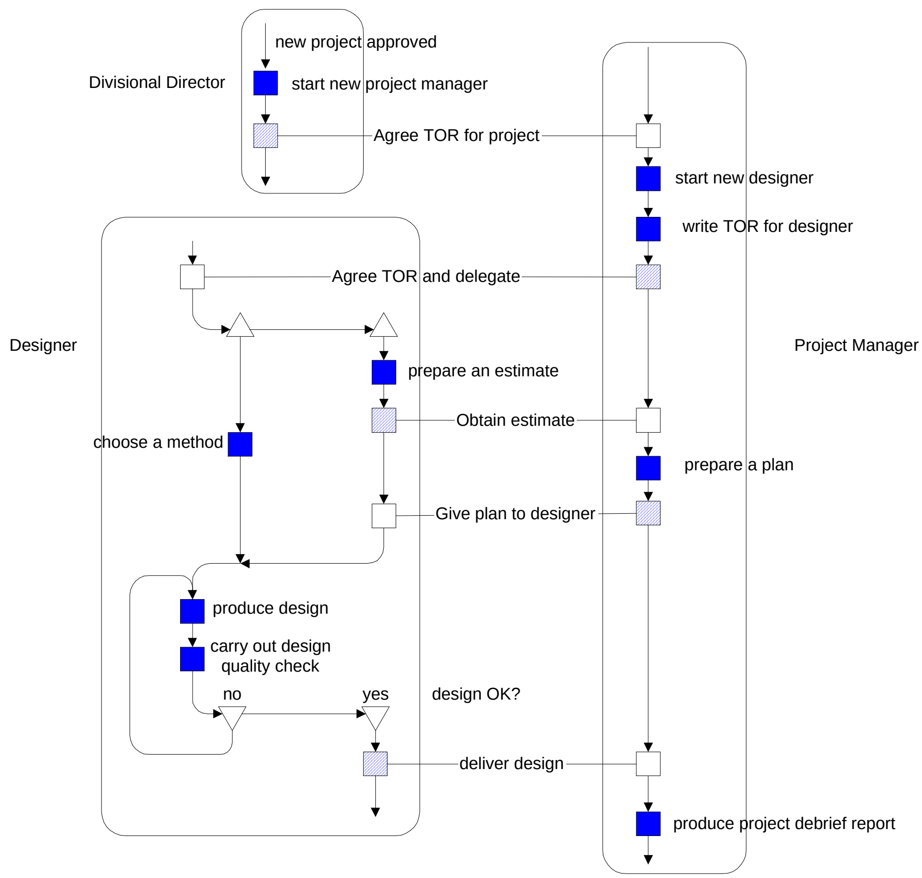

Figure 1: Example Role Activity Diagram

Note that roles are like *type*s or *classes* in that they describe a particular kind of behaviour, but are *not* instances of that behaviour. There may be a number of such roles acting in parallel at any given time. For example, in a retail outlet, there might be a number of customer instances and a number of cashier instances. Similarly, a single role may be acted out by a number of different people at different times.

3. Quantitative Analysis of RADs

One approach to analysis of process models involves the use of heuristics such as those proposed by Ould [6] for RADs. In order to facilitate more objective application of these heuristics, various counts have been identified to expedite this form of analysis [1, 7]. Consider a familiar concept for software engineers: coupling. Ould argues that within business processes — as with software — it is advantageous to minimise coupling. It is thus necessary to understand how coupling is manifested in RADs and to consider whether coupling heuristics are appropriate for business processes. Ould states that:

> *'As a set, the roles should be loosely coupled, i.e. we should expect few interactions between them'.*

Taking these comments about coupling to the extreme implies that the perfect process model contains a single role. However, this role would contain many unrelated tasks and would thus reduce the cohesiveness of that role. Ould observes of cohesion in RADs:

> '*A role should have high cohesion, that is, the activities that form it should be closely related and collectively have a single purpose'.*

This implies that the role is purposeful and that processes are designed such that a group of tasks is largely self-contained. A role that had many unrelated tasks (low cohesion) would need to communicate with a greater number of roles in order to further the process and would thus often have high coupling. Roles communicate and synchronise only when necessary, however, some separate groupings (roles) are required to maintain cohesiveness[2]. Hence, though one may wish to minimise coupling, some level of coupling (owing to interaction among roles) is unavoidable. The discussion of what constitutes an appropriate level of coupling is further discussed in relation to the empirical work described in the subsequent section. Suffice to say we do not advocate "magic number" thresholds, nor the optimisation of one heuristic or design feature to the exclusion of all others.

The activity *'carry out design quality check'*, performed by the Designer role in Figure 1, is internal to that role, and involves no communication with any other role. These internal activities are known as actions within RADs. In contrast, the interaction *'give plan to designer'* is a communication between two roles, in the case of the designer example, between the Designer and the Project Manager roles. Counts of these actions and interactions, (of each action or interaction

[2] Given that cohesion is a semantic construct we have not pursued trying to measure it.

square), form the basis of our proposed RAD coupling measure. An interaction between role *X* and role *Y* is, therefore, counted as a separate interaction for each role, i.e. it represents two interactions, since an interaction square is counted in each role. In other words, role X interacts with Y and Y interacts with X, hence two interactions. The 'Role Coupling Factor' (CpF) of X is calculated by forming the following quotient:

$$CpF_X = (I_X) / (A_X + I_X).$$

where I_X is the count of interactions in role X and A_X is the count of all actions, again, within X. If a role has only actions, that is it engages in no interactions, the coupling factor will be zero. In practice, this is highly unlikely, since the role would play no part in the remainder of the business process. Similarly, if the role has no actions and only interactions (it is viewed as passive) then the coupling factor is one. This is relatively common as will be seen from the following case study. It is theoretically possible to have a role with neither interaction nor action. However, such a role would have no impact upon the business process. For such a case, the role is viewed as a separate system with the coupling factor undefined.

As an illustration of how coupling factors can be obtained from a RAD, consider the Divisional Director role in Figure 1. It has one interaction and one action, hence, the coupling factor is 1/2. The analysis of the remaining roles is summarised in Table 1.

Role	A_X	I_X	CpF
Divisional Director	1	1	1/2
Projector Manager	4	5	5/9
Designer	4	4	4/8

Table 1: Quantitative Analysis of Coupling in an Example RAD

In this example, the coupling factors are similar for each role. One aim in the design of RADs would, therefore, typically be to consider the degree of coupling between roles and explore alternatives. Reducing coupling allows roles to become more autonomous and, hence, because they no longer have to synchronise with other roles, gives them the opportunity to complete their tasks more quickly with less opportunity for delay as a consequence of waiting upon other role instances. This type of analysis allows the process modeller to compare alternatives. It also draws the modeller’s attention to roles that have abnormally high, or perhaps low levels of coupling. In the case of the process analysed above, we see little evidence of any abnormal role.

In addition to the Role Coupling Factor (CpF) a system-coupling factor (SysCpF) is defined to be:

$$SysCpF = (I_{sys}) / (A_{sys} + I_{sys}).$$

where I_{sys} is the count of all interactions within the RAD and A_{sys} is the count of all actions within the RAD. For Figure 1, the system coupling is therefore 10/19. The system-coupling factor has an identical range of values to that of the role-coupling factor, i.e. between zero, if there are only actions and no interactions, and one, if there are only interactions and no actions.

However, the usefulness of measures can only be gauged properly by their empirical evaluation. The following section describes a case study, which uses RADs to model business processes and coupling metrics to aid in the analysis of those models. Although a significant focus of this paper is the heuristic to reduce role coupling, in practice this cannot be considered in isolation. Coupling can always be minimised by the simple expedient of subsuming all activities within a single role. Clearly, such a process would be highly undesirable.

4. A Case Study

In this case study, we examine the process of gaining new business for a large developer of telecommunications software. This covers the process from the initial enquiry through bids, to customers placing orders. The organisation concerned suggested examination of this process because it was felt to be inefficient and problematic despite representing a key part of the business.

The business is relatively innovative, with a range of products, which are configured to meet the needs of their clients. These clients are typically telecommunications companies. The division of the company where the work was carried out employs over 500 software engineers, and has a traditional top-down management structure with relatively bureaucratic processes.

In order to examine the prescribed or theoretical process a number of documents were examined. The result was three sequential diagrams each representing one of the three sub processes:

New Business Process
Bid Decision
Bid Preparation

Each process is linked by their final and initial states, which are intended to coincide with natural breaks in the process, for example, awaiting business opportunities, the qualification of a business opportunity, the launch of a bid (and subsequent preparation) and the submission of a proposal.

In addition to modelling the theoretical process, information on the actual process was derived from interviews with process actors. These interviews used semi-structured questions and walkthroughs of the RADs produced from the analysis of documents.

The approach of building theoretical and actual process models would lead one to conclude that there should essentially be two contrasting views. That is, a model of the procedures (based solely on study of procedures documents), and a model of the actual process (based upon interviews). In practice, however, modelling proved to be more complex since different process actors had significantly different views of the process, which in turn differed from the official or documented view.

To illustrate our ideas of quantitative analysis we describe our analysis of nine sub-processes that relate to the overall process of gaining new business.

Variable	**Mean**	**Median**	**Min**	**Max**	**Sum**
Roles	11.22	12	6	18	101
Act	5.78	4	1	14	52
Int	27.22	26	11	40	245
Act+Int	33	32	14	50	297
SysCpF	0.83	0.80	0.72	0.97	n.a.

Table 2: Summary Data for Processes Studied

Table 2 provides some idea of the complexity of the nine process models. Note that the raw process data may be found in Appendix A. Combined, these comprise a total of 101 roles, 52 actions and 245 interactions. The high proportion of interactions to actions is striking and confirms the highly coupled nature of the process. The typical process has 12 roles, 4 actions and 26 interactions.

In this case study, we focus upon the contrasting views of the process from two different users: Business Support and Proposal Producers.

Variable	**Mean**	**Median**	**Min**	**Max**
Act	0.51	0	0	12
Int	2.43	1	1	14
Act+Int	2.94	1	1	24
CpF	0.96	1	0.33	1

Table 3: Summary Data for Roles Studied

Table 3 shows summary data of an analysis by role of counts of actions, interactions, total activities (i.e. actions plus interactions) and the role coupling factor. From the median figures it is clear that a typical role is small comprising a single interaction, however, there are a small number of large, complex roles. The largest role — the Bid Manager — has 12 actions and 12 interactions. The next largest role — the Business Support Specialist — has 8 actions and 14 interactions.

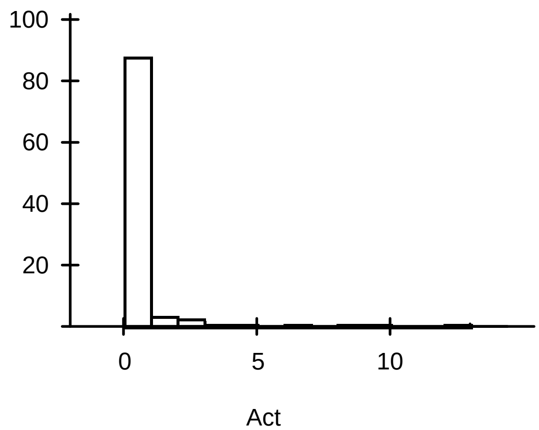

Figure 2a: Histogram of Actions

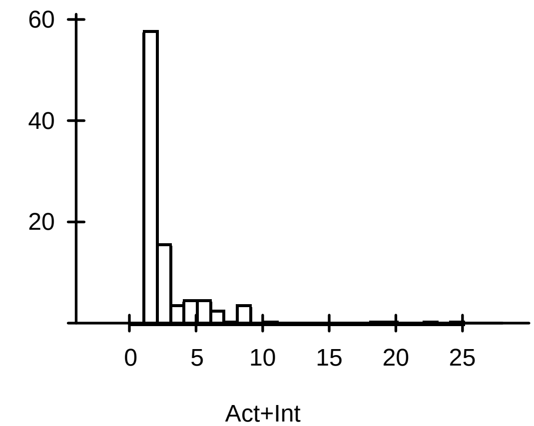

Figure 2c: Histogram of Activities

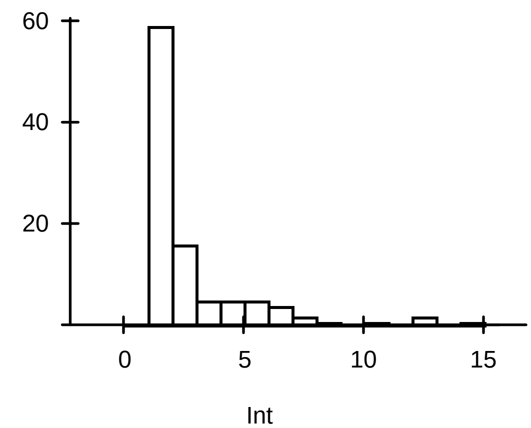

Figure 2b: Histogram of Interactions

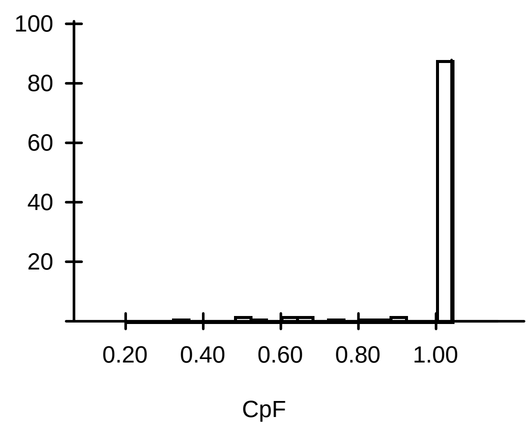

Figure 2d: Histogram of Role Coupling Factor

Figures 2a to 2d show the distribution of values for the above measures. Actions, interactions and, naturally enough, total activities show a pronounced positive skew. By contrast, the coupling factor indicates a negative skew with unity being both the median and modal value.

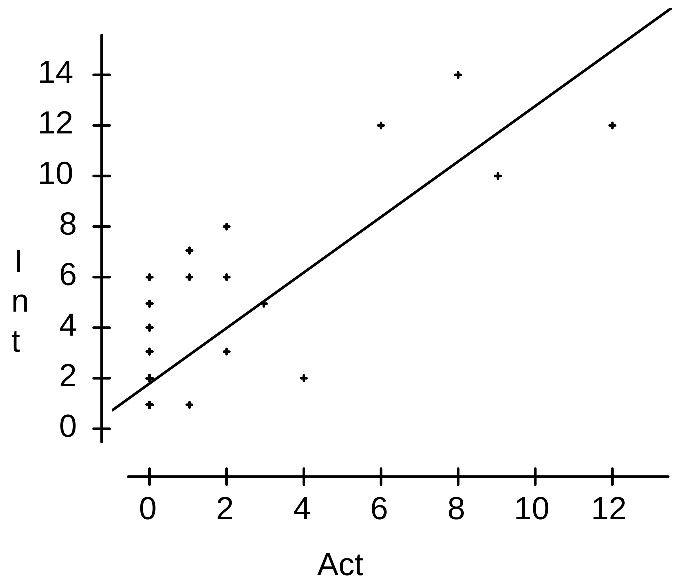

Figure 3: Scatterplot of Actions v Interactions

Figure 3 indicates that there is some relationship between the number of actions and the number of interactions but also that a number of roles comprise interactions only. There are, however, no roles that comprise actions only. From the scatterplot it is clear that there are a small number of unusually large, or outlier, roles.

Perspective	**Process**	**Roles**	**Act**	**Int**	**Act+Int**	**CpF**
Theoretical	Commercial	Bid Manager	12	12	24	0.50
Business Support	Bid Preparation	Business Support Specialist	8	14	22	0.64
Theoretical	Order Processing	Commercial Proposal Group	9	10	19	0.53
Theoretical	Bid Preparation	Proposal Specialist	6	12	18	0.67

Table 4: Four Largest Roles

Table 4 shows that the four largest roles have relatively low coupling factors, compared to the remainder. This is because the majority of other roles have zero actions. However, in other respects the four roles are large in that they contain many activities. The Business Support role is particularly noteworthy in that has no less than 14 interactions with other roles.

It is therefore not surprising that process actors felt that the overall process was bureaucratic: "a paper chase". These actors estimated that over 50% of their time was spent in chasing signatures (of which too many were required). This problem was exacerbated when it was unclear who was the designated signatory in cases where the original signatory was unavailable. Of all the problems, there appeared to be a consensus that chasing information and particularly signatures was the major cost to time and effort. One process actor likened themselves to "an autograph hunter", and stated that at times it felt as though the process was designed "so that nothing could get out".

Perspective	Process	SysCpF	Ints per Role	Mean Role Sz
Proposal	Bid Preparation	0.786	1.83	2.33
Proposal	Bid Decision	0.929	2.89	3.11
Support	Bid Decision	0.750	1.33	1.78
Support	Bid Preparation	0.800	2.86	3.57
Theoretical	Order Processing	0.719	3.83	5.33
Theoretical	Commercial	0.720	2.77	3.85
Theoretical	Bid Preparation	0.833	2.22	2.67
Theoretical	New Business	0.957	1.83	1.92
Theoretical	Bid Decision	0.972	2.69	2.77

Table 5: Comparison of Role Coupling and Size among Processes

This view of the process is supported by Table 5. Here we see that in processes such as Bid Decision that the system coupling factor (SysCpF) is close to unity from both the theoretical and proposal perspective, although curiously not from the support perspective. The process contains almost no action type activities.

Rather than allowing individual roles to take responsibility for activities most have shared responsibility and are carried out 'by committee'. This leads to delays, both in scheduling, and in carrying out the tasks. Indeed, such delays associated with interaction were the motivation for Ould's [5] suggestion that role coupling should be minimised. However, it was the huge number of single interaction roles that drew the most comment, these often being accounted for by the need for signatures or authorisations. It seems unlikely that all of the signatures needed (over 25) during the process of going from enquiry to submission of proposal were essential. This could be prioritised and rationalised so that some of the signatories are removed, and so the process user can spend a higher proportion of their time in actually composing the bid proposal.

Another aspect of this case study is the three different perspectives of the process. These are the "theoretical" or documented view, the business support view and the proposal view. Quantitative analysis can support the comparison of the different views.

Perspective	Roles	Act	Int	Act+Int	SysCpF
Proposal Bid Preparation	6	3	11	14	0.786
Support Bid Preparation	14	10	40	50	0.800
Theoretical Bid Preparation	18	8	40	48	0.833

Table 6: Comparison of Different Bid Preparation Perspectives

We now consider the three views of the Bid Preparation sub-process. As Table 6 reveals, the differences between the three perspectives of, at least in principle, the *same* process is quite striking. For example, both sets of process actors consider there to be fewer roles than the documented process. This may be because the distinction between roles (e.g. Proposals Specialist, Technical Specialist) is less apparent to process actors — who often act multiple roles anyway — than diagrams or procedures suggest. There is also a tendency for process actors from one perspective to simplify those parts of the process conducted by other parts of the organisation. This simplification takes the form of reducing the process to simply the interactions. This may explain in part the large discrepancy between the Proposal perspective upon Bid Preparation as compared with the Support view. It may also have the effect of inflating the proportion of interactions to actions. Having said this, even the documented or theoretical perspective still gives strong evidence of a highly coupled process. The implication from these differing views of the same process is that there is a need for improved communication of how the process is intended to function and who is doing what.

This analysis has focused upon simple counts of actions and role coupling. There are, however, other aspects of a RAD that one might wish to explore quantitatively. For example, we have not differentiated between driving interactions and non-driving interactions. This might be useful for identifying roles that tend to be passive and hence more vulnerable to waiting. Other avenues that we do not explore in this paper include part and case refinement, parallel threads and iteration. These are all within-role features that might potentially be analysed.

In summary, this quantitative analysis suggests an overly coupled process, with a very high degree of communication and interaction between roles. Qualitative investigation of the process, by interview and workshops confirmed this view. The investigation revealed a highly bureaucratic process where few activities could be carried out by roles independently and where the essential actors in the process spent at least 50% of their time in gaining approval for documents. Hence, a redesigned process was recommended which allowed roles far more autonomy in the bidding process, and significantly reduced the coupling and cycle time. The analysis has also identified significant problems of perception and means of improving communication of the process between different participants is recommended.

Although such conclusions could have been reached by qualitative analysis by an expert, the use of simple measures allows this analysis to be more efficient and to quickly highlight areas of concern. Furthermore, it is the authors' experience that the presentation of measures increased the strength of argument for process change to the organisation concerned.

5. Conclusions

This paper proposes the idea of applying measures, based on simple counts, to aid the analysis of static process models. The use of such measures facilitates the quantification of heuristics to support analysis of process models. This has been illustrated by a quantitative analysis for a set of RADs that describe the process for obtaining new business for a large telecommunications systems supplier. Since the models are non-trivial, we have argued that quantitative techniques complement the more traditional qualitative analysis methods that process modellers typically deploy.

The last thing the authors wish to do is to suggest that the various measures described should be adopted as new process complexity metrics. Instead, the usefulness of these simple counts, in identifying real world problems, is intended to demonstrate the effectiveness of the general strategy of applying counts to static process models. This case study indicates that measures may be useful in helping to identify 'outlier' roles. That is, roles that exhibit particularly high (or low) levels of coupling for their role type within an organisation or site. These measures have coincided with the views of the process actors who have been concerned about the excessive levels of role interaction and consequent potential for delay. The quantitative analysis also highlights the marked differences in three views or perspectives of the same process. This indicates problems in communication.

The main theme of this paper is that there is potential for the application of simple counts to static process models. Although we have focused upon some simple counts appropriate to a particular notation, we believe the ideas have more generality. It is felt that the preliminary work described in this paper suggests that there is merit in further research, particularly into the interaction of different sets of heuristics. For example, we have noted that role coupling can always be minimised by subsuming the entire process into a single role. This course of action would lead to problems with other process desiderata. The authors also recognise the need for *both* quantitative and qualitative methods to analyse and restructure static business process models. An important role of quantitative analysis is to draw the modeller's attention to particular issues within complex models. It is our view that quantitative analysis can augment the set of analysis tools available to the process modeller.

References

[1] Chen, L., *An Empirical Investigation into Management and Control of Software Prototyping, PhD Thesis,* in *Department of Computing*. 1997, Bournemouth University:

[2] Curtis, B., M.I. Kellner, and J. Over, 'Process Modelling', *Communications of the ACM*, 35(9), pp75-90, 1992.

[3] Handy, C. *On Roles and Interactions,* in *Understanding Organisations*, Penguin: 1976.

[4] Miers, D., *Use of Tools and Technology within a BPR Initiative,* in *Business Process Re-engineering: myth and reality,* C. Coulson-Thomas, Editor, Kogan Page: 1994.

[5] Ould, M.A., *Business Processes: Modelling and Analysis for Reengineering and Improvement*. Wiley: 1995.

[6] Ould, M.A. and C. Roberts. 'Modelling Iteration in the Software Process', in *Proceedings of the 3rd International Software Process Workshop*. Breckenridge, Colorado, USA: IEEE Computer Society Press, 1986.

[7] Phalp, K.T., 'The CAP Framework for Business Process Modelling', *Information and Software Technology*, 40(13), 1998.

[8] Potts, C., ed. *Proceedings of the First International Software Process Workshop*. IEEE Computer Society Press: Egham, Surrey, England, 1984.

[9] PROCESS, *PROCESS: Modelling and Mapping the Business Process*. 1997, EPSRC project, home page at: http://www.staff.ecs.soton.ac.uk/~ph/process.html.

[10] SEBPC, *Systems Engineering for Business Process Change: Managed research programme of the Engineering and Physical Sciences Research Council (EPSRC). Homepage at: http://www.staff.ecs.soton.ac.uk/~ph/sebpc/*

[11] Yourdon, E., *Modern Structured Analysis*. Prentice-Hall International Editions, Prentice Hall: 1989.

[12] Yourdon, E., *Object-Oriented Systems Design: An Integrated Approach*. Prentice-Hall International Editions, Prentice Hall: 1994.

Appendix A: Process Data

Perspective	Process	Roles	Act	Int	Act+Int	SysCpF
Proposal	Bid Preparation	6	3	11	14	0.786
Proposal	Bid Decision	9	2	26	28	0.929
Support	Support Bid Decision	10	4	12	16	0.750
Support	Bid Preparation	14	10	40	50	0.800
Theoretical	Order Processing	6	9	23	32	0.719
Theoretical	Commercial	13	14	36	50	0.720
Theoretical	Bid Preparation	18	8	40	48	0.833
Theoretical	New Business	12	1	22	23	0.957
Theoretical	Bid Decision	13	1	35	36	0.972