

INTERNATIONAL DESIGN CONFERENCE - DESIGN 2010  
Dubrovnik - Croatia, May 17 - 20, 2010.



## HOW CAN PD PROCESS MODELLING BE MADE MORE USEFUL? AN EXPLORATION OF FACTORS WHICH INFLUENCE MODELLING UTILITY

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*Keywords: design process model, process model utility, cybernetics*

### 1. Introduction

A significant body of research exists in the area of Product Development (PD) process modelling. This is highlighted by Browning and Ramasesh (2007), who recently reviewed over 400 papers in this field. However, despite hundreds, probably thousands of publications in this area, few methods appear to have been widely accepted by industry as practical approaches to improve PD processes. To improve the attractiveness of process modelling and model-based methods to industry it is thus worthwhile to ask: In what sense is PD process modelling useful? and how can the utility of modelling be improved? In this paper, we approach these questions through an analysis of PD process modelling ‘utility’ – which in broad terms we consider to be the degree to which a model-based approach or modelling intervention benefits practice. We view the utility of modelling as a composite characteristic which depends both on the properties of models and on the way they are applied. The paper draws upon established principles of cybernetic systems in an attempt to explain the role played by process modelling in operating and improving PD processes. We use this framework to identify eight key factors which influence the utility of modelling in the context of use. Further, we indicate how these factors can be interpreted to identify opportunities to improve modelling utility.

The paper is organised as follows. Section 2 provides background and motivation by discussing an example of PD process modelling practice. After drawing on this real-life example to formulate the main research questions considered in the paper, Section 3 outlines our choice of a theoretical/analytical approach to explore them. Section 4 begins the analysis by introducing some basic concepts regarding modelling, and explains how the utility of modelling as understood herein depends on interactions between the model, the modeller, and the system being modelled. Section 5 draws upon established principles of cybernetic systems theory to incorporate this view in an explanation of the role of modelling in PD process operation and improvement. This framework is used to define modelling utility and to progressively identify influences upon it. Section 6 reflects upon the scope and applicability of the analysis, highlighting implications for researchers and practitioners in PD process modelling. Section 7 concludes.

### 2. Motivation

This section describes some of the challenges surrounding PD process modelling through a real-life example. The case study is an archetypical example of process modelling in industry, intended to highlight the need for a clearer definition of modelling utility and thereby clarify the motivation of this paper.

The case study, described in detail by [Kerley et al. 2009], involved development of a flowchart-style workflow model of the early conceptual design process in a large UK aerospace manufacturer. The

objective of the modelling intervention was to facilitate development of a new conceptual design process, which was required to shift the emphasis of life-cycle engineering considerations in the company in response to changing business objectives.

In Kerley et al.'s study, a process model was constructed through an iterative process in which the modeller (a university researcher and colleague of the authors) conducted interviews with domain experts in the company. During each interaction, a description of the process was discussed, critiqued and annotated. The modeller then incorporated the agreed changes into the next version of the workflow model and the process was repeated. Ultimately, by revisiting this cycle among different members of the design team, an agreement on the form of the 'as-is' design process was developed. Prior to modelling, this coherent understanding did not exist in any external and accessible form. A 'to-be' model of the redesigned process was subsequently developed by following a similar iterative approach. Previously unknown new activities required in the revised process were identified and localised in the model. Discrete-event simulation was then used to estimate the time and cost of the revised process. This revealed that the desired changes would result in too great a cycle time, so trade-offs were made and the 'to-be' process model was further refined until the desired changes and projected performance of the new process were in accord.

Kerley et al.'s analysis of this case study highlighted the iterative nature of modelling and process knowledge creation, in which different levels of formality, modelling tools and knowledge elicitation methods were brought to bear in order to meet different objectives as the modeller's and domain experts' understanding of the problem increased and converged [Kerley et al. 2009]. The understanding generated through modelling was expected by the company to assist in subsequently implementing their improved process.

To summarise, PD process modelling is a complex activity in which many decisions are embedded. In this case, such decisions included: what modelling notations to use; how to elicit knowledge; how to structure the model; when to stop modelling; and what assumptions to incorporate in simulation. The premise of this paper is that a better understanding of the factors which make process modelling more, or less useful could help modellers approach these decisions in a more informed way.

### 3. Research questions and approach

The complexity of the modelling process and the many decisions which must be made within it indicate the need to better understand how these decisions impact on the utility of modelling notations, modelling approaches and model-based methods to operate and improve processes. Understanding modelling utility is important both to modellers and researchers:

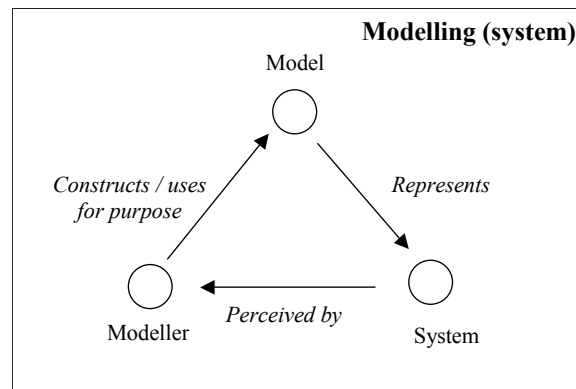
- **For modellers:** How should decisions during PD process modelling be approached to maximise utility of the modelling process?
- **For researchers:** Can areas of research be identified which could lead to significant improvements in the utility of PD process modelling practice?

In this paper we explore these questions by analysing the relationship between PD process modelling and the process it is used to operate and improve. We aim to discuss this relationship in an abstract way, relatively independently from the forms of the model and the process.

To do this, we draw upon the principles of cybernetic systems theory to analyse PD process modelling in a way which abstracts from the operative problems associated with applying particular modelling notations, tools, and approaches to given domains. We argue that stepping back in this way could help achieve a systematic analysis of the factors influencing model utility, highlighting new perspectives by avoiding a focus on topical issues or on problems encountered in particular modelling exercises. This analysis is intended to support and complement practice-oriented research into how process models should be developed and used, such as that presented by Kerley et al. (2009) following analysis of the case study described above.

## 4. Background

This section draws upon the literature and the case study to introduce the aspects of modelling which are subsequently incorporated in our analysis. These aspects and the relationships between them are depicted in Figure 1 and described below.



**Figure 1. Aspects of modelling**

### 4.1 Systems

PD processes are widely described as systems in the literature (e.g., [Pulm 2004]). However, the term ‘system’ covers a range of ideas, since many diverse situations have been described in this way [Jackson 2000]. For instance, Checkland (1981: 112) describes several attempts to propose a typology of systems. He goes on to argue that in order to understand systems, a distinction should be made between transcendental systems which are beyond knowledge, natural systems, and designed systems. According to Checkland, the category of designed systems includes designed physical systems, designed abstract systems such as scientific theories, and human activity systems.

In the context of our analysis, a useful distinction is that between ‘inorganic’ systems – those with which engineering is traditionally concerned – and ‘organic’ systems. We view PD processes as organic systems, such as designers, processes, organisations and markets, interacting with and constrained by inorganic systems – including the artifacts being designed, the physical laws which govern them and the IT systems around which processes operate. To clarify, characteristics of both system types are highlighted in Table 1.

**Table 1. Characteristics of ‘inorganic’ and ‘organic’ systems**

<b>Inorganic systems (e.g., Natural physical, designed physical)</b>	<b>Organic systems (e.g., Natural, designed abstract, human activity)</b>
Artefacts, IT systems etc.	Biological systems, ecosystems, social systems, systems of ideas etc.
Often described in terms of parts, subsystems and hierarchies	Often described in terms of substrates, boundaries and ‘ecologies’
Often engineered or designed – in which case, emphasis on ‘being created’ and providing function	‘Evolved’ – emphasis on existence and ‘becoming’
Emphasis on internal structure and interfaces, which are ‘hard’ and ‘imposed’	Emphasis on boundaries, which are ‘soft’ and ‘self-determined’
Each ‘physical element’ typically forms part of one system, although that could be viewed from multiple perspectives	Each ‘physical element’ may provide many substrates and participate in multiple systems. Interactions occur between systems on different substrates
Behaviour governed mostly by ‘hard’ constraints of structure and physical laws	Behaviour governed mostly by ‘soft’ constraints of environmental interactions

## **4.2 Models**

As with 'system', 'model' is an overloaded term used to refer to a broad range of concepts, both in colloquial and academic usage. A model may be unique to an individual or shared amongst a group. It may refer to something which is tied to a particular physical medium, such as clay; a particular way of representing, such as the Gantt chart; it may be internalised within the mind of an individual; or it may be an abstraction for something which is distributed among a number of individuals and artefacts. An external model may be formal, such as a mathematical or simulation model, or informal, such as a flowchart. In this paper, we consider all models which participate in the operation and improvement PD process systems, regardless of the nature of those models. We view process models of the type constructed during the case study of Section 2 to be partial expressions of a more complex, distributed and socially negotiated scheme.

## **4.3 Representation**

In the literature there is so little agreement on the nature of modelling that this area has been termed the 'model muddle' [Wartofsky 1979]. However, two ideas appear common to all concepts of modelling; a model must somehow represent a target system and, in the context of representation is in some sense less than that system [Edmonds 1999]. It is usually agreed that the most important aspect of a model is not its form, but how it is used to represent – i.e., how it is interpreted by one system as a proxy for another. This is true of all modelling systems, not only those which involve conscious human modellers.

## **4.4 The modelling process**

Hubka and Eder (1992: 101) define the modelling process as incorporating all activities that form a part of developing a model, including the development of the modeller's perception/imagination. In PD process terms, the modelling process often does not have a defined beginning and end; a given modelling intervention builds on existing knowledge and/or representations, and forms part of an ongoing process of reflection and improvement. In the remainder of this paper, the term 'modelling' is therefore used to denote the ongoing process of making models and applying them for a purpose.

## **4.5 The purpose of modelling**

It is often stated that models must be built for a purpose, and that the purpose has significant impact upon a model's form and scope. Since PD process models can be developed for many different objectives, a generally-applicable analysis of modelling utility should be based on a statement of purpose which includes all these objectives.

A key concept in systems theory, especially that pertaining to organic systems, is understanding how the system responds to change. PD processes can be said to be self-regulating systems, in that they contain mechanisms which control the impact of exogenous and endogenous changes. For instance, if a project is running behind schedule, its participants will take action to re-plan; as new technology becomes available, ways of working continuously evolve or are re-designed around it; and as the business environment changes, processes and organisational structures change in response. In our view, the purpose of PD process modelling is to generate knowledge which can contribute to system regulation. This concept forms the basis of the forthcoming analysis.

## **4.6 Summary**

To summarise, process models may be viewed as abstractions of a system which represent aspects of that system to enable its regulation. It follows that models and modelling agents should be considered part of the systems they represent and whose behaviour they govern; a model such as a workflow model participates in an ecology of models which enables regulation. In turn, the utility of modelling can be said to be related to the quality of regulation it enables. We therefore base our analysis of modelling utility on cybernetics, an established framework of thought which offers a general explanation of the role of models in system regulation.

## 5. A cybernetic perspective of PD process modelling utility

Our analysis of modelling utility is organised as follows. Firstly, we explain how cybernetics theory is applicable to both hard and soft systems, and therefore to PD process systems as characterised in Section 4.1. We then more clearly define modelling utility in the cybernetic sense, prior to reviewing some basic principles of cybernetic systems and showing how they can be interpreted in the context of PD process modelling. The subsequent sub-sections each examine a different aspect of cybernetics, thereby progressively identifying influences on modelling utility. In Section 6, we reflect on the applicability and scope of these insights.

### 5.1 Definition of process model utility

In overview, cybernetics is concerned with understanding how systems are, or can be controlled through regulation of their behaviour in the presence of uncertainty, disturbance and changing objectives [Ashby 1954]. Cybernetic systems theory has been established and formalised for many years in the engineering discipline of control system design, which focuses on inorganic systems. The application of cybernetic principles as an analytic approach to examine organic systems is also well-established, for instance in the field of management cybernetics [Beer 1972, Jackson 2000]. Three so-called cybernetic principles provide the definition of model utility used in this paper:

1. **The principle of feedback.** The most basic characteristic of a cybernetic system is that change occurring in the system or its environment is manifested as information, which is subsequently used to determine the system's response, which in turn creates further change. This forms a closed 'feedback loop' of change and reaction.
2. **The principle of teleonomy.** Cybernetic systems are teleonomic – they can be said to have objectives. This is true of all cybernetic systems, not only those which are explicitly designed to meet a purpose. In general, the objective for regulation can be said to be imposed by the system's participation in the functioning of a higher-level system [Checkland 1981].
3. **The principle of optimality.** Definitions of optimality are always related to the system's teleonomy. Considering a water tank with inlet flow governed by a ball valve, for instance, optimality could be related to the time taken for the water level to return to the desired value following a disturbance in the outlet flow. The cybernetic perspective and key principles outlined above lead to the high-level definition of process modelling utility which forms the core of our argument:

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A system incorporating high-utility modelling allows that system to respond to both exogenous and endogenous changes in a way which results in observed behaviour remaining close to desired behaviour.

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In forthcoming subsections, factors which impact upon PD process modelling utility as defined above are progressively identified. Our analysis is based largely on an interpretation of the view of organisational processes as cybernetic systems put forward by Argyris and Schön (1996).

### 5.2 Principles of cybernetics

The cybernetic perspective outlined above can be considered in the context of different parts of a system, and of different perspectives of its decomposition. For instance, it could be interpreted as a framework describing how a process participant responds to observations of their environment or, as in this paper, used to analyse the collaborative process of constructing and using a PD process model to operate or improve a process.

In the organisational context, Argyris and Schön write of 'theory-in-use'. This comprises the heuristic rules of thumb which are used to select the strategy of action to be pursued to obtain a desired result in any given situation. The desirability of a result is determined by the values and norms held by the organisation. Considering these ideas, two main 'cybernetic principles' pertaining to the effectiveness of a regulated system are:

- **The principle of requisite knowledge** [Heylighen 1992]. This states that effective regulation requires an accurate model of the effects of one's actions. In other words, on each

change-action loop an action is selected from the range of possibilities based on predictions of its outcome. The principle of requisite knowledge states that selecting an action which is exactly optimal requires that the model used to make these predictions has a level of complexity requisite to that of the system under regulation.

- **The principle of requisite variety** [Ashby 1954]. Whereas requisite knowledge refers to the fidelity of the model, in this context requisite variety refers to the ability not only to select, but also to carry out an appropriate action, placing constraints on actuators as well as models.

Consideration of these principles highlights three factors which influence modelling utility:

<b>U1</b> Detection	The utility of modelling is limited by the ability to detect deviations from the ideal behaviour.
<b>U2</b> Knowledge	The utility of modelling is limited by the extent of knowledge about the system; i.e. the fidelity of the model.
<b>U3</b> Actuation	The utility of modelling is limited by the ideality of the effector; i.e. the ability to act out recommendations across sufficient range of action.

### 5.3 Principles of single-loop learning

Interpreting these ideas in the context of self-organising systems such as PD processes, as these systems seek to adapt to an ever-changing environment they can be said to *learn*. Learning uses feedback about system performance to improve the model which governs response to stimuli. Single-loop learning as described by Argyris and Schön (1996: 20) corresponds to changes to strategies and action in such a way that leaves the ‘values of a theory of action’ unchanged.

Process improvement is therefore associated with learning, whereas process operation is associated with feedback of the type described in Section 5.2. To clarify this distinction, consider the situation in which quality control inspectors identify a defective product and convey that information to production engineers, who, in turn, may change product specifications. From a PD process perspective, a detected error or defect, defined as an outcome mismatched to expectation, has been corrected through feedback.

During learning, in contrast, a connection is made between the detected error and the model – i.e., the processes or organisational strategies of action – which are intended to keep the organisation performing in a way which meets certain norms and values. In this context, norms and values can be thought of as the criteria used to evaluate the goodness or value of a process.

In terms of process operation and improvement, since a model is only a limited abstraction of the system it requires updating when advice derived through that model, or through knowledge gained in the modelling process, does not cause the process performance to respond in the anticipated way. This could be viewed as refinements in understanding of the results of a given action, and thereby to the way actions are selected in response to observations. To summarise:

<b>U4</b> Reflection	The utility of modelling is limited by the ability to recognise when advice derived through modelling does not have the desired effect, to reflect upon the modelling to understand why, and to revise the modelling accordingly.
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### 5.4 Principles of double-loop learning

Argyris and Schön (1996) further distinguish between single- and double-loop learning – a distinction borrowed from Ashby's “Design for a Brain” [Ashby 1954]. In double-loop learning, the connection is made between 1) the observed effect of action; 2) the models or strategies which guide action; and 3) the values and norms by which strategies are selected.

Values and norms themselves may change over time. To illustrate, consider the case study described in Section 2. As the aero-engine industry recently moved from a product- to service-related business, the criteria by which a PD process is judged effective also changed; it is no longer sufficient to focus on the predictability of the development process and the cost and weight of the resulting product, but it is also increasingly important to consider the life-cycle value which is generated. The operational models which were previously effective are no longer ideal in the new business context. Although

change in this example was imposed by a major shift in market context, double-loop learning is likewise concerned with the ongoing process of reflection and noticing that values must gradually shift over time to take advantage of the evolving context and new opportunities.

Values and norms do not only change through external factors. Strategies may change concurrently with, or as a consequence of, change in values [Argyris and Schön 1996: 21]. As the organisation evolves in conjunction with its competitors, customers and supply chain it has opportunities to influence the environment, especially in the highly interconnected world of complex product and service development. To summarise:

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<b>U5</b> Alignment	The utility of modelling is limited by the ability to align the objectives and success criteria for modelling with the higher-level objectives of the process or organisation, and to the objectives of other modellers.
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### 5.5 Principles of the model and modeller remaining within the system boundary

The cybernetic systems view is a theoretical construct; a functional, rather than physical or topological view of the elements which comprise a system. It does not make statements about the form a model can take – the definition of ‘model’ in a cybernetic sense encompasses all constructs which take part in determining a system’s response to its environment.

Furthermore the cybernetic perspective neither requires nor implies any similarity of structure between a model and the system it represents. According to the definition given in Section 5.1, different models may result in equally-optimal systems. A model is viewed as a black box device which provides a transfer function used by a system to determine its response to observed phenomena. It allows an output signal, defined in terms of the allowable actions within the system, to be determined from an input, specified in terms of observations of the system state.

In other words, a model is not outside the system boundary. Rather, it should be viewed as part of the system it describes, since it determines the system behaviour and must be described in the language of observable meaning and conceivable actions [Heylighen and Joslyn 2001]. No model can therefore be assumed to provide an accurate view of the system, since all stimuli which can be used to improve it are transformed or filtered in some way by the perceptual apparatus. In a physical system, for instance, a ‘learning’ model can only be improved by consideration of data from the sensors. For the same reasons, participants in a system have ‘blind spots’ they cannot see [von Foerster 1979].

The importance of considering this influence on a model’s utility may vary. One way to improve fidelity of a model or modelling approach is to consider the limitations of a modelling approach with respect to its ability to represent phenomena known to occur in reality. This is appropriate for exploring those modelling problems in which ‘hard’ models of ‘hard’ domains build theory on top of observations or on top of other, accepted theories. While appropriate to many domains, this approach is difficult to apply to models of complex, human-centric processes because the reality being modelled is complex and subject to interpretation. In other words, such problems can be viewed as modelling ‘soft’ systems in a ‘hard’ way. The resulting models are generally acknowledged to be selective simplifications [Deutsch 1952]. Since there is no well-defined system of principles or laws governing the domain of interest, even though the model itself may be formal it is difficult to analyse the ability of a model to represent that domain. Due to this difficulty, it may be concluded that limitations of the perceptual and conceptual apparatus used to observe the environment have potentially very significant impact on modelling utility in the PD process context. To summarise:

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<b>U6</b> Perception	The utility of modelling is limited by the perceptual and conceptual filters which determine what is available for inclusion in a model.
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### 5.6 Principles of parsimony

‘A model is a map, not the territory’. While being a limitation of models which can affect their utility, this is also an important aspect of modelling – taking away or abstracting the complexity of a real system to highlight certain factors which are most pertinent to decision-making according to the system’s objectives. In the context of mathematical or simulation modelling, for instance, it is necessary to determine a small set of assumptions and variables in order to render analysis tractable.

Finding an appropriate way to do this is often not obvious when a modeller is faced by complex, ambiguous situations such as human-centric processes. To summarise, the utility of modelling is limited by the modellers' ability to develop appropriately parsimonious representations:

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U7 Abstraction	The utility of modelling is limited by the ability to choose which of the factors and phenomena perceived to impact upon the objectives should be considered, and what importance should be given to each.
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### 5.7 Principles of homeostasis

The ability of a system to preserve stability of response under changing conditions is often referred to as homeostasis. For complex systems such as PD processes to remain stable in the face of change, subsystem stability is necessary but not sufficient. Despite stable subsystems, interactions of the system with the environment can still lead to instability of the overall system. Another driver of instability is emergent behaviour, such as changes arising from within the system itself.

Stability in the face of disturbance and changing objectives is not only important to system performance, but also to other factors which influence the utility of modelling. In particular, enhanced stability may assist learning by making it easier to identify whether modelling interventions actually result in improved performance. This is especially important when the system and its environment are continuously changing and when many models are in operation concurrently.

In the context of process modelling, one way to enhance stability is to undertake modelling interventions as a continuous process rather to implement change in large steps, such that cause and effect can be more easily identified and adjustments may more easily be made. To summarise:

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U8 Responsiveness	The utility of modelling is limited by the delay between observation and action, and by the responsiveness of reflection and learning.
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### 5.8 Summary

The eight utility factors outlined above each limit the ability of a modelling system to respond to change, both exogenous and endogenous in origin. In addition to highlighting these factors, the cybernetic perspective of PD process modelling also provides a framework which supports and integrates many of the concepts introduced in Section 4. In particular:

1. It is not meaningful to separate the regulator from the regulated process, since the design work itself and the organisation of that work are essentially indivisible. Thus, the PD process, models and modellers can all be considered part of a self-regulating system.
2. An implicit model of the process always exists in the perceptions of the modelling agents. They use this knowledge to regulate the process in which they participate.
3. Construction of a process model such as that described in Section 2 can be viewed as refinement of this implicit model, driven by participants in the process making judgements regarding the value of their knowledge with respect to its ability to regulate the observed performance of the system.

The framework we have presented does not include an explicit analysis of the relationship between the ecology of models and the regulated system; in other words, it does not provide insight regarding the form of those models or how they should be constructed and managed to maximise benefit. In the following section, we therefore discuss how the cybernetic perspective can be interpreted to provide more specific guidance to researchers and practitioners.

## 6. Scope and applicability

As with other branches of systems thinking, cybernetics aims to provide an explanation of *all* systems and does not focus on any one domain. Consequently, influences U1 to U8 identified in Section 5 are stated in very abstract terms. This is both a strength and a weakness of using an analytic approach to investigate modelling utility: a strength, since the analysis is not limited to any one PD process



modelling approach; and a weakness, because the resulting insights require interpretation in each context of use to provide useful and concrete guidance.

In the following sub-sections, we first clarify the scope of our analysis by considering different outlooks on modelling, types of model and purposes for modelling, arguing that a cybernetic view of modelling is relevant to all these cases. We then illustrate how our findings may be applied to give more concrete guidance to researchers and practitioners, by considering how influences U1 to U8 could be interpreted in the context of the case study of Section 2.

### 6.1 Applicability to different outlooks on modelling

Many different approaches which use modelling to support or improve PD processes have been reported in the literature (see, e.g., [Browning and Ramasesh 2007] for a review). These approaches can be broadly divided into two groups, according to the outlook of the modeller:

1. **Predictive modelling.** A model is constructed to derive unknown, or difficult-to-measure properties of a specific process from known or measurable properties. These may then feed directly into operation or improvement of that process. In common with many industry applications, the case study described in Section 2 was largely concerned with predictive modelling, since specific guidance was developed directly for a specific case.
2. **Explanatory modelling.** A model is used as part of a ‘thought experiment’ intended to generate a better understanding of the relationships between levers and their effects, thereby helping human participants in the process to make better decisions. Although modelling may be based on a real-life process or case study, the understood intent is to generate knowledge which is widely-applicable. Many applications of process modelling reported in the academic literature are explanatory in outlook, especially those concerned with process simulation.

Cybernetic systems theory helps explain how both forms of modelling are involved in process regulation through the same basic mechanism – generation of knowledge which influences decisions in the process. For both predictive and explanatory outlooks, it can be said that the model as an artefact is ultimately only a by-product of the modelling process; the purpose of modelling is to create knowledge about a PD process or class of processes which could subsequently contribute to improvement and operation.

For instance, the development of a process model such as that described in Section 2 can be viewed as one stage in an ongoing activity of process operation and improvement – i.e., of developing knowledge which may be used to regulate PD projects and ultimately the company with respect to organisational objectives arising from the business environment. This ongoing activity is likely to incorporate a range of modelling approaches and levels of formality.

### 6.2 Applicability to different types of PD process model

Many different types of PD process model have been proposed in the literature. These span significant conceptual differences, such as the distinction between soft systems and hard systems methodologies, or the distinction between activity network simulation and system dynamics simulation. More subtle differences are also evident, such as those between the wide range of closely-related activity network modelling notations such as BPMN, EPC, UML, etc. Similarly, many authors have developed PD process simulation codes which are based on similar, yet different assumptions. In this subsection we argue that the cybernetic explanation of modelling is applicable to all these cases.

All the models, regardless of type, can be viewed as based on the same principle that although PD processes are often difficult to understand, due to characteristics such as uncertainty, complexity and adaptiveness, they nevertheless have a structure or ‘architecture’ which remains relatively stable and can be modelled. For instance, the order of attempting activities in many PD projects is difficult to model, as it is influenced by in-situ decisions and obscured by the iterative complexity of workflows. Nevertheless, this order is constrained by more stable factors such as the required information flows between activities; by the product architecture; by the organisational structure and established ways of working within a company; and by the objectives of the PD project. Each type of process model

mentioned above, and many others, can be said to represent certain stable elements of process architecture which constrain change.

To illustrate, this representation can be approached in different ways. For instance, Hubka and Eder (1992: 102) distinguish between two different types of model: behavioural and structural. In the PD process context, an example of a behavioural model is the system dynamics ‘rework cycle’ model used by Ford and Sterman (1998) and others. Rework cycle modellers consider the stable element of process architecture to be the structure of feedback mechanisms which govern project progress. On the other hand, structural models take, for example, information dependencies between activities in a process or the relationship between different components of a product to be the most stable aspect of a process architecture [Lindemann et al. 2008, Eppinger et al. 1994].

Although the details are different, all the approaches aim to help understand aspects of project behaviour through representing process architecture. As mentioned earlier, the content or means of representation of any given model is not explained by cybernetics theory. However, in a cybernetic sense different types of model could be considered to generate different types of knowledge which can assist in the regulation of different aspects of process performance; in terms of different objectives for regulation as well as different means of implementing control actions. The many regulation requirements and actuation possibilities within a complex process are met through an interlocking ecology of models, mixed between mental models, shared models, and external models.

### 6.3 Applicability to different purposes of PD process modelling

Throughout this paper we have referred to modelling to operate a PD process vs. modelling to improve that process. We argue these can be viewed as different forms of regulation, differing mainly in terms of the actuation possibilities which are considered. For instance, whereas process operation might be concerned with the best way to prioritise work to deliver a project within a certain schedule, process improvement might consider how the activities themselves could be reorganised to leave more leeway for such prioritisation in future. In the latter case, any actions taken might also require change in other models as they become outdated. Depending on situation, the use of models for different purposes could be viewed either as an interlocking system of feedback loops covering a continuous spectrum of actions with interacting causes and effects, or as a hierarchy of regulation systems.

### 6.4 Illustrative example

To illustrate how these insights can provide concrete guidance to improve modelling utility, we considered influences U1-U8 in the context of applying task network simulation of the type described in the motivating example. The resulting analysis is summarised in Table 2. While some of the resulting issues are commonly considered in practice and have been thoroughly explored in the PD process modelling literature, others – such as the need for instrumentable metrics and the tendency for the modelling notation to bias the modeller – are often given less prominence. The example therefore illustrates how the cybernetic approach can provide a checklist for modellers as well as pointers for further research topics which could improve modelling practice.

**Table 2. Interpretation in the context of task network simulation modelling**

<b>Influence</b>	<b>Definition</b>	<b>Interpretation</b>
<b>U1</b> Detection	<i>The utility of modelling is limited by the ability to detect deviations from the ideal behaviour.</i>	Identify concrete and instrumentable process metrics which modelling will focus on and aim to improve.
<b>U2</b> Knowledge	<i>The utility of modelling is limited by the extent of knowledge about the system; i.e. the fidelity of the model.</i>	Ensure that the model reflects the observed process as closely as possible, for instance through triangulation of stakeholder perspectives.
<b>U3</b> Actuation	<i>The utility of modelling is limited by the ideality of the effector – the ability to act out recommendations across sufficient range of</i>	Ensure that recommendations sought through modelling are implementable and that stakeholders are motivated to

	<i>action.</i>	implement them.
<b>U4</b> Reflection	<i>The utility of modelling is limited by the ability to recognise when advice derived through modelling does not have the desired effect, to reflect upon the modelling to understand why, and to revise the modelling accordingly.</i>	Recognise that modelling may not deliver benefits immediately, but is an ongoing process which requires reflection and readjustment. Ensure participants in the modelling process are aware of this and maintain commitment over extended period.
<b>U5</b> Alignment	<i>The utility of modelling is limited by the ability to align the objectives and success criteria for modelling with the higher-level objectives of the process or organisation, and to the objectives of other modellers.</i>	Ensure that the objectives of the modelling exercise are aligned with company objectives and with the objectives of other modellers working in the company.
<b>U6</b> Perception	<i>The utility of modelling is limited by the perceptual and conceptual filters which determine what is available for inclusion in a model.</i>	Consider how the chosen modelling approach may bias participants views of the system, especially if they are unfamiliar with process modelling, and thus influence the structure of a model and the conclusions which are ultimately drawn from it.
<b>U7</b> Abstraction	<i>The utility of modelling is limited by the ability to choose which of the factors and phenomena perceived to impact upon the objectives should be considered, and what importance should be given to each.</i>	Identify a range of factors which could be included in a modelling exercise. Reflect upon whether the choice of scope, and factors to focus on is appropriate and ensure it is guided by the modelling objectives.
<b>U8</b> Responsiveness	<i>The utility of modelling is limited by the delay between observation and action, and by the responsiveness of reflection and learning.</i>	Short modelling cycles delivering immediate feedback, and incremental improvement may be more beneficial than large projects which are slow to complete.

## 7. Conclusions

Many authors have proposed that Product Development (PD) processes can be improved through modelling. In any process modelling exercise, conducted in the laboratory or in industry, difficult questions arise regarding the fidelity of the model and, consequently, regarding the degree to which recommendations derived from it should be trusted. This paper has argued that modellers should aim to maximise the utility of their interventions rather than the fidelity of their models, where utility is influenced by a model's application as well as its quality. We describe the utility of modelling as the quality of process regulation which it enables.

Drawing on established principles of cybernetic systems theory, the paper has analysed the concept of modelling utility to explain the role of modelling in regulating PD processes. This approach allows identification of the different influences involved in governing a system's behaviour, without immediately specifying how these influences are embodied in the physical world. One benefit is that the resulting insights are on a level of abstraction suitable for application to any modelling approach or intervention. Another is that basing the analysis on a well-developed and accepted theory should help avoid a focus on specific operative problems and should allow more systematic identification of a set of influences. On the other hand, this high level of abstraction also presents difficulties in drawing concrete, implementable recommendations from the theoretical insights.

The explanation of PD process modelling through cybernetic systems was used to identify eight influences on modelling utility. To summarise, they are: 1) The ability to detect deviations of the modelled system from its ideal behaviour; 2) Achieving adequate fidelity in the model; 3) Being able to act out recommendations derived through modelling; 4) Reflection on the observed utility of modelling; 5) Selecting an appropriate objective for modelling; 6) Achieving appropriate perception of the target system, recognising the tendency of modelling approaches to focus attention on those issues they clearly represent; 7) Including an appropriate projection of these observations within the limited

representation of a model; and 8) Modelling, implementing insights and reflecting with sufficient responsiveness. To illustrate application of these guidelines, each was interpreted in the context of task network modelling. This illustrates how the cybernetic analysis can provide a checklist for modellers as well as pointers for research which could improve modelling practice. With further development, we believe this framework of analysis could highlight many opportunities to enhance task network modelling methods and increase their potential to benefit practice.

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