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Operations management and systemic modelling as frameworks for BPR

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Introduction

During the period elapsing since Michael Hammer's seminal paper (1990) business process reengineering (BPR) has emerged as a key, albeit controversial issue of concern at both the strategic and operational levels. It is also the case that the advent of BPR has coincided with a continued resurgence of interest in operations management (OM) accompanied by a much stronger strategic focusing of the subject (Harrison, 1993; Skinner, 1985; Voss, 1992). The combination of these factors implies that operations now features clearly on senior management's agenda, ranking in importance alongside strategy and organisation (Stacey, 1996).

BPR is a controversial subject but irrespective of its ultimate long-term fate as an explicit change-management concept the usefulness of the business process perspective appears unassailable. Hence, as the lateral, process view of business displaces the traditional functionalist paradigm, it is entirely sensible to initiate that reorientation from the wider perspective of the transformation systems model which underpins the operations domain. Within this systemic perspective it may be argued that the operations boundary may be redefined to include virtually all stages in the primary value-activity-chain of Porter's model (1985) as depicted in Figure 1, with the exception of marketing. It may also be considered to subsume several support functions while clearly overlapping and interfacing, to a substantial degree, with virtually all of the others (Slack *et al.*, 1995). The operations discipline is therefore clearly of pivotal interest to any observer who wishes to view organisations from a systemic, process-oriented perspective.

However, the complexity of organisational life, in terms of process, structure and dynamic interconnectivity, implies that the unassisted human mind is probably incapable of retaining and manipulating sufficiently representative models during reengineering projects. The reason for this is that when redesigning organisational processes and structures, migration from the current to the intended state involves the "navigation" of transitionals which may be particularly difficult to anticipate and control. Hence the behaviour of dynamic systems during such transient regimes is inherently much more complex and less intuitive than the corresponding behaviour in static systems or those which are in dynamic-equilibrium. Consequently, events unfolding during the transient can render achievement of the new, target steady state, unattainable.

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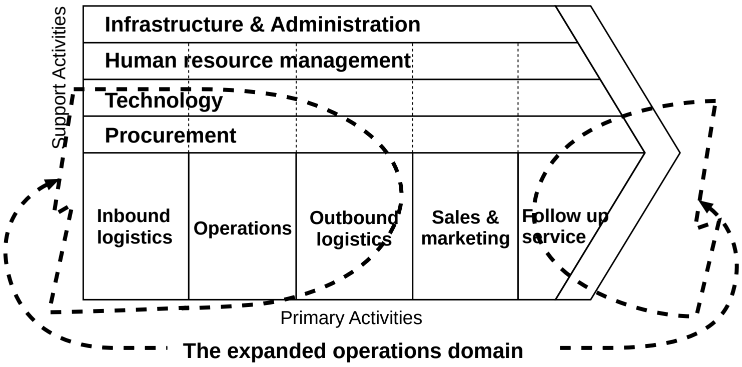

Figure 1.
Porter's value chain

When viewed in this way it is hardly surprising that so many BPR initiatives yield disappointing results as these dynamic, non-linear characteristics may not always be transparent to, or fully understood by, BPR practitioners. Furthermore, with social and business systems the time-constants can be typically of the order of months, years and in some cases decades, making cause-and-effect analysis and accountability particularly difficult.

Hence it is recognised that in taking a systemic view, the core, cross-functional business processes such as product-delivery, product-development, customer-acquisition and staff recruitment, retention and development, may all be viewed as interacting, closed-loop, dynamic sub-systems, collectively possessing complex characteristics. Upon recognising that such systems can potentially be represented by dynamic models which can, in turn, be translated into highly aggregated continuous system simulations, managers are positioned within reach of potentially powerful tools which, if accepted and methodically implemented, can provide the distinctive competitive advantage which is the target of typical BPR initiatives (Warren *et al.*, 1995).

Furthermore, it has been demonstrated that the theory and practice of simulation is now sufficiently mature to support widespread uptake by practising managers operating within contemporary commercial and industrial frameworks (Morecroft, 1992; Morecroft and Sterman, 1992; Richmond and Peterson, 1990; Senge, 1990; Sterman, 1987; 1989; Wolstenholme and Stevenson, 1994). Hence it is argued that simulation has now emerged as an important tool in the process of organisational learning and change-management, focusing on the strategic, as well as the operational level of intervention. This approach, it is argued, should therefore come to be seen as the source of an instinctive underpinning framework, on which BPR initiatives should be founded as a matter of course.

Hence the purpose of this paper is, in summary, to present a perspective on the theory and practice of process management which is founded in the systemic, dynamic-simulationist paradigm. It is argued that this presents a realistic approach to both large-step and small-incremental improvement change-management initiatives based on process-modelling, assisted by recent developments in information technology. Most importantly this approach focuses upon the core values and techniques of contemporary OM in both manufacturing and services. By this means, it is proposed that the success rate of BPR initiatives may be improved, thereby addressing many of the problems outlined above.

Process improvement and competitive advantage

Approaches such as BPR recognise that business performance is ultimately dependent on the optimisation of core and support business processes. In this respect it shares much in common with TQM, differing fundamentally in the sense that objectives are achieved by fundamental, large step changes in process rather than by incremental, continuous improvements. In the methodology for attainment of competitive advantage, as discussed in this paper, the three key interacting factors to be considered are business process orientation, systems thinking and organisational learning. These are respectively elaborated upon as follows.

Business process reorientation and change management

The term business process re-engineering (Hammer and Champy, 1993) has emerged as the generic descriptor of the various approaches to large-step, change management initiatives which have emerged during the last decade. Its fundamental tenet is that attention should be concentrated on the core business processes, and their linkages, which add value in the eyes of the customer.

Processes comprise sequences of linked activities which cross the vertical, functional boundaries existing in most organisations. Hence the re-engineered organisation transforms itself from a structure based on departmental roles to one based on directly servicing processes as depicted schematically in Figure 2. During this transformation new processes may be redefined from scratch, often using new developments in technology to perform tasks in fundamentally different ways.

Few management theories are without critics and considerable debate surrounds the efficacy and compatibility of approaches such as BPR (Blackburn, 1996) and the earlier change-management technique of total quality management (TQM). However, irrespective of whether the incremental, continuous

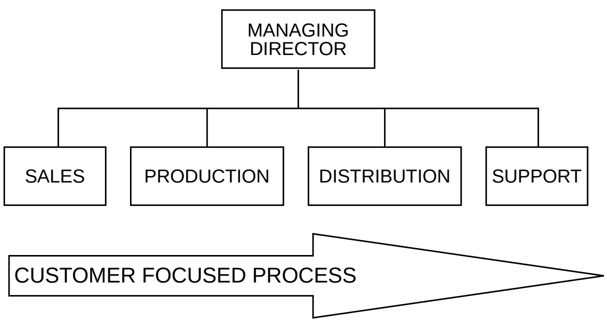

Figure 2.
Functional vs process-oriented structures

improvement orientation of TQM or the radical step-change rigour of BPR is adopted, both approaches retain, at their core, the concept of process. By definition this implies flows of inputs, resource transformations and delivery of outputs and since these rarely occur at equal rates, accumulation elements must be provided in the system. Hence they may be considered to contain inertia.

Furthermore, typical business systems will usually contain multiple process stages cascaded together, some of which will lie outside the organisational boundary. Delays of various kinds (queues, conveyance, dead-bands and hysteresis) will also be present thereby adding to dynamic complexity. Non-linearities further complicate the picture as outputs are not always proportional to inputs. Such non-linearities may appear either as stark discontinuities or as more gradual saturation arising due to physical or other limits in the system.

Finally, business systems are replete with feedback loops which may be either physical or informational. In many cases it may not be immediately obvious that such loops exist and in others, distortions, non-linearities and delays in the information path may produce outcomes which are clearly at odds with the original intentions of the process designer.

Core and support processes. The generic, interacting but explicit, core business-wide processes typically include:

- Product delivery (production).
- Product/service innovation and development.
- Customer acquisition, retention and development.
- Order fulfilment.
- Supply-chain management.
- Strategy formulation.
- Decision making.

It is suggested (Richmond and Peterson, 1990) that if more than five core processes are identified, during the business process analysis, then it is likely that functions or tasks are being confused with core-processes. The test to be applied is to check that the process actually extends across an entire spectrum, typically starting with customer interest arousal and running through to customer satisfaction. For convenience, core processes may be subdivided into two or three sub-processes but care must be taken to ensure that these are seamlessly integrated at the boundaries, if the full impact of process orientation is to be secured.

In addition to core processes a number of essential, generic support processes may also be identified such as:

- Financial management.
- Human resource (HR) acquisition, development and retention.
- Information system management.
- Operations support and administration.

It may be noted that at first glance the above processes may appear to map directly onto classical departmental functions. However, on closer scrutiny, it is apparent that they actually extend across several departments. For example, product-delivery may involve sales, distribution and purchasing departments as well as production. Order-fulfilment involves production, accounting and purchasing as well as marketing. Similarly "human-resource acquisition and development" involves integrated interfacing with the respective functions to which staff are ultimately allocated, and is not purely an activity of the HR department. Such process re-orientation can therefore become a significant challenge to contemporary organisations when contemplating BPR.

Systems thinking as a tool for analysis and design

The view of business as a system and BPR as a reconfiguration tool, has been briefly portrayed above, in the introduction. Hence "systems theory" or "systems-thinking" is well established in the literature and is potentially highly applicable in operations and strategic management (Coyle, 1977; Lyneis, 1980; McClelland, 1992). Such systems and their associated "toolbox", simulation, may therefore be envisioned as lying on a spectrum as depicted schematically in Figure 3. Along this continuum, applications potentially range from control-engineering, at the so called hard-end of the system, to strategic and human resource management at the soft-systems end (Fowler, 1995; Sterman, 1989). The central band comprises discrete-event simulation which is particularly familiar in the context of design and control of factory layouts (e.g. Fowler and Lees, 1995; Harrell and Tumay, 1996; Popplewell and Bonney, 1978).

The gap existing between applications at the respective ends of this continuum is also characterised by a gulf between the classical tools available for problem solving and decision support. At one extreme reside the quantitative techniques of operations research, while at the other end are the more "qualitative approaches" which are, in practice, more widely used by most general managers.

However, when undertaking major change-management initiatives, as exemplified by BPR, managers are required to grapple with complex issues which possess both spatial and temporal dimensions and the combination of

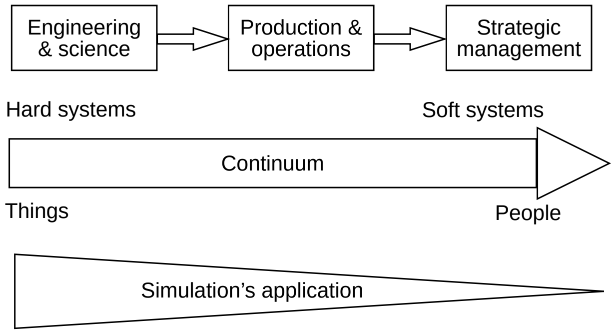

Figure 3.
The systems spectrum

these factors produces dynamic scenarios which are difficult to conceptualise using traditional approaches. While qualitative methods may be extremely flexible they are relatively lacking in precision, resolution and repeatability and may lead to seriously flawed analysis. However, the classical quantitative approaches also have serious shortcomings which has resulted in them becoming virtually discarded by many managers. Hence the respective weaknesses in both the quantitative and natural-language based, qualitative methods may be summarised as follows:

(1) *Quantitative methods (OR etc.):*
- Too abstract.
- Culturally alien to many managers.
- Models are too simplistic.

(2) *Qualitative approach:*
- Messy and ambiguous.
- Imprecise and verbose.
- Fashion-led, transient and "guru-oriented".

As a result managers of strategy are potentially left with a somewhat limited toolkit with which to perform the demanding tasks of business process innovation and design. However, in recognising these shortcomings it is proposed that simulation potentially provides a linking bridge between the hard and soft ends of the systems spectrum which ensures that the strengths of both qualitative and quantitative approaches are harnessed while simultaneously mitigating some of their respective weaknesses. This is an increasingly important requirement in BPR since this is an activity which is typically located towards the right-hand end of the systems spectrum, being associated with strategic management in an holistic context while simultaneously requiring detailed understanding of underpinning business processes.

Organisational learning

It has been argued that the ability to learn faster than one's competitors is the only real, lasting competitive advantage that an organisation can achieve (De Geus, 1988). This reflects the view of Drucker (1994) that information will be the key business resource of the future. It follows that ability to acquire, discriminate, analyse and learn from the business information available, constitutes a core requirement in the quest for competitive performance management which is the target of so many change-management initiatives.

Systemically, the attainment of the organisational learning and process improvement targets may be depicted as shown in Figure 4. Competitive performance management is thereby depicted at the intersection between the three spheres.

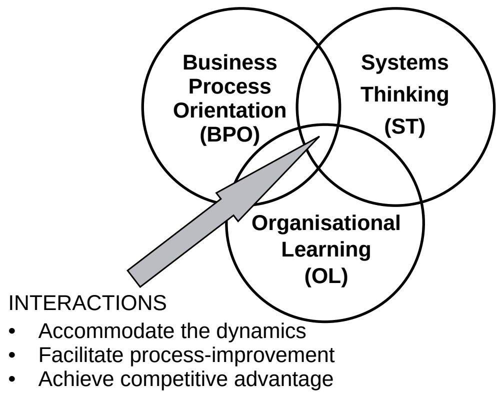

Figure 4. Competitive performance management

(1) "Systems-thinking (ST)" and its associated theories provide both a philosophy and a set of methods.

(2) "Business process orientation (BPO)" provides a clear focus on the real value-adding processes and distinguishes whether these are direct or supportive.

(3) Finally "organisational learning (OL)" represents the formulation of perspective and the dissemination, retention, and adaptation of principles.

The relationships between these factors may be made more explicit using influence diagram notation as presented in Figure 5. Relationships are thereby seen to be typically circular rather than sequential. Hence an ST approach helps initially to analyse, clarify and redesign business processes while simultaneously enhancing organisational learning by providing disciplined thinking and a structure within which to relate and understand interactions between dissimilar entities.

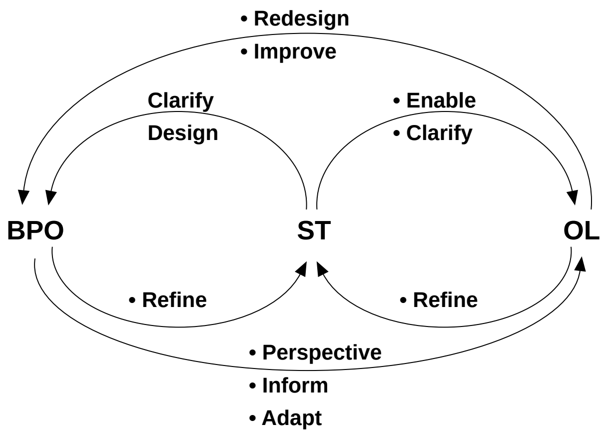

Figure 5. Process improvement influence diagram

BPO feeds, in turn, back into the systems methodology as experience is gained during implementation and operation. Likewise the BPO informs and provides perspective to the organisational learning dimension. As a result of organisational learning, further improvements and redesign of business processes may unfold, and so on.

The role of operations in core business processes

A central theme proposed in this paper is that in searching for fruitful organisational learning experiences a focus on OM which in one form or other ultimately lies at the heart of the value adding process, provides a natural perspective within which to proceed. Minimally, the operations function must establish close working relationships and porous boundaries across which information, people and materials can flow smoothly to virtually every other function within the business. Alternatively, in its expanded role, operations may actually subsume many of these roles within itself. For example, contemporary human resources management (HRM) theory advocates pushing out many of the activities traditionally associated with "personnel" into the operations domain. Management accounting and its associated budgetary and cost-targeting activities are similarly closely concerned with the operations function. Likewise, contact with customers need not always occur directly through marketing but could often be addressed directly by operations. In fact the closer awareness of product-structure and process concepts, which should instinctively exist in operations may, in the final analysis, be of irreplaceable added value to the customer.

Meanwhile the convergence of operations with departments such as design, R&D, product development and engineering has for some time been strongly promoted through approaches such as simultaneous or concurrent engineering. Finally the role of purchasing, procurement and supply-chain management, which is firmly keyed into the production value-chain, is clearly an area for extensive overlapping or even subsumption of activities. Hence the critical role of the operations perspective is central in organisational redesign with its concomitant requirements for re-definition of boundaries, reconfiguration of interfaces and introduction of appropriate control mechanisms.

The customer-focused product delivery process

The interactions and boundary definitions linking operations with other functional departments may be systemically represented as shown in Figure 6 which depicts the core product-delivery process. This representation shares much in common with the view presented by Slack *et al.* (1995, p. 25). The diagram also alludes to the issue of operations boundary definition. The minimalist view would contain operations to the central block whereas a more expansionist and systemic view expands the boundary as shown and extends the domain of operations, to some degree, into virtually all of the contiguous organisational functions.

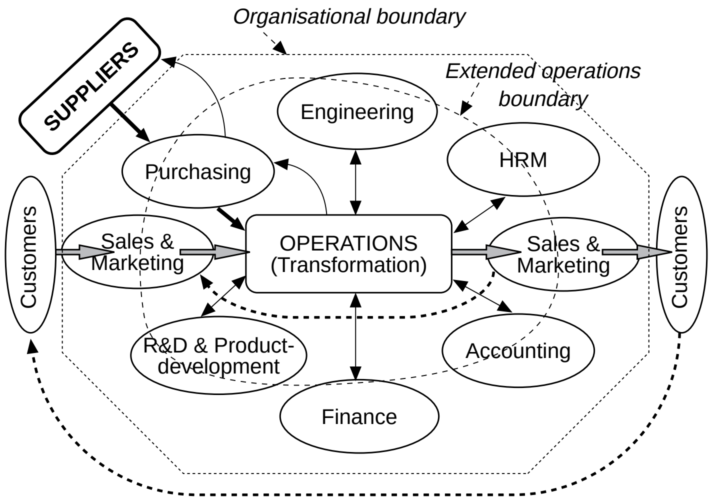

Figure 6.
The product delivery process

In keeping with the tenets of BPR, Figure 6 also portrays the customer-facing perspective. Hence the primary process-flow commences with, and ends with, the customer. Notably sales and marketing have been banded together in this high-level view and appear in the primary process flowline with all other internal functions providing support processes.

Other important features evident in Figure 6 are the feedback linkages which transform the core processes from a set of linear sequences into a network of interactive closed loop circular processes. The main feedback would traditionally occur from the customer, through the marketing/sales interface, and hence into product-development and operations. However, additional feedback, directly from sales to operations and product-development, may also be envisaged. The advantage of incorporating such direct linkages is that time-delays and attenuation or distortion in the communications process may be mitigated with salutary effects throughout the system.

Increasingly the role of the supply-chain and the potential for deriving competitive advantage from its effective management, is also recognised in contemporary literature (Lamming, 1993). However, the basis on which these external functions are incorporated into the system may prove more complicated than is the case for internal functions. A feedback loop from operations to the external supplier, via purchasing, is therefore shown in Figure 6, establishing the basis of a systemic synthesis of this important and topical dimension.

The final point concerning this closed loop model of the customer delivery value chain is that it must be treated as a dynamic system. Time delays and inertia are inevitable in the various physical and informational processes depicted. The system therefore exists in a state of perpetual change and owing to the existence of feedback is always, in accordance with the principle of classical feedback theory, potentially subject to dynamic instability and other complex behaviour (Towill, 1992; Towill and Naim, 1993).

The problem is that, while individual parts of the system may be well understood within the local domain of their own particular functionality, the overall systemic implications in a closed loop, networked configuration such as this can be deceptively elusive, unpredictable and even counterintuitive. These complications are compounded by the long time-constants often experienced in business and management systems. This means that effects often materialise at some location, remote from the point of initiation and displaced in time, often by months and possibly by years. As a result, causality sequences are usually very difficult, if not impossible to trace. Hence the role of simulation may be highly efficacious when contemplating reconfiguration of this core business process as it potentially provides a preview of unfolding dynamic events which are effectively preordained by the structure and dynamic characteristics of the system.

The product development process

While the primary generic business processes depicted in Figure 6 was customer-focused product-delivery, the parallel core business process of product-development exists as an alternative perspective depicted in Figure 7. The same array of departmental functions appears, but their configuration is now adapted to accommodate the new emphasis. The process is once again customer-facing and in this case, although marketing and sales is still banded as one unit, the marketing function takes precedence, as contrasted with selling.

The process commences with the marketing function identifying customer requirements and transmitting these forward to R&D and product-development. Within the expanded operations environment, product-development is seen as an integral component of operations and is conducted in parallel with process development, supported by engineering. Financing of the product and production process development appears next in the forward path.

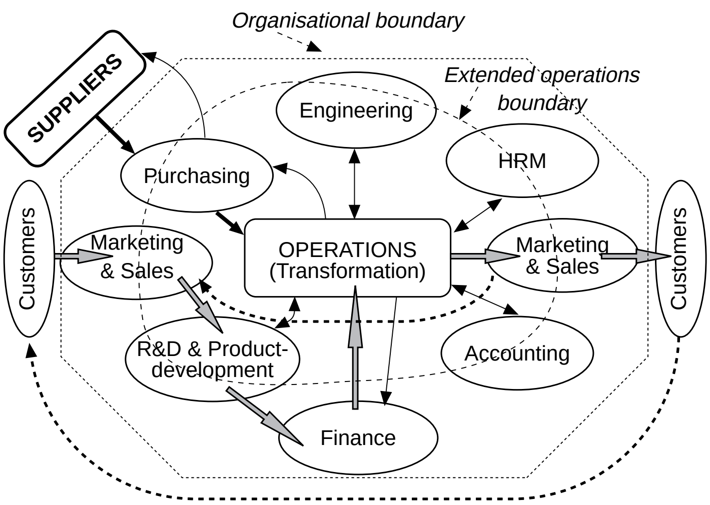

Figure 7. Operations and the product development process

Finally the new product is delivered from operations, through the marketing and distribution channels and on to the customer.

In reviewing the models in Figures 6 and 7 it is important to recognise that it is by no means certain that all the elements in the system will display linear characteristics in terms of the relationships between inputs and outputs. "System-gains" or "transfer-characteristics" (Towill, 1984) may vary continuously and smoothly and they may also experience sign inversion if, for example, saturation of an element leads ultimately to a "fish-hook" type of input/output relational characteristic. The effect of such a sign-inversion, with respect to the rate of change (or first derivative) in the transfer characteristic, is that it can effectively convert a stable, negative feedback system, into an unstable positive feedback one. Likewise transfer characteristics may be subject to discontinuities, saturation and rate-limiting implying a potential for radical variations in system performance from one point in time and state, to the next.

The strategy development process

The third generic management process which is readily depicted in this context is the process of strategic management itself. This is presented in Figure 8 which again shows a customer-oriented focus with the customer "topping and tailing" the internal organisational processes.

Strategy evolves in response to analysis of the environmental and marketing-oriented factors on one hand and operations (resource capabilities) on the other. Hence the specification of policy is akin to the setting of demand levels in the control systems analogy. The associated decision-making sequences may similarly be conceived within a systemic, process-oriented context, as classical "control-compensation" activities. The evolution of strategy may therefore be seen to be a highly iterative, non-linear and dynamic process with critical

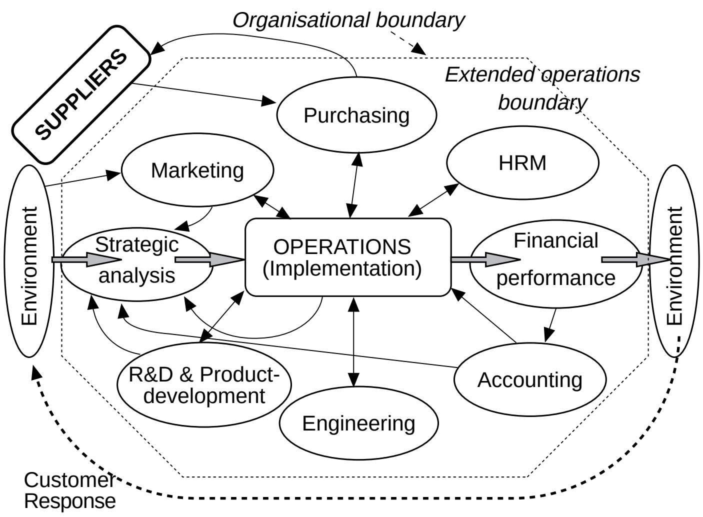

Figure 8.
Operations and the strategy development process

implications for operations as it is at the operational level of implementation where strategy inevitably either succeeds or fails. Hence operations is once again encountered directly in the core process path with other departmental interfaces occurring as shown in Figure 8.

Finally the performance, or outcome of the strategic management process is usually measured in financial terms by accounting procedures so that another feedback link is thereby established between the system output and the strategic "set point" as defined in the strategic analysis block.

However, in the "environment", external to the organisation and outside the immediate boundary of the controlled system model, is the customer, whose satisfaction is arguably the ultimate output of the "supra-system" which is "the organisation". Hence the outer system loop is established as before.

The supply chain management process

The final example concerns the issue of supply-chain management which was raised briefly in the context of the product-development and product-delivery processes above. This has now come to be recognised as a crucial business process in its own right involving operations and strategy at the highest level (Jones, 1990; Lamming, 1993; Lester, 1992; Slack *et al*., 1995). Hence it is observed that the process-view of business extends naturally into contiguous value-chains outside the business boundaries and as organisations increasingly seek strategic alliances and just-in-time (JIT) arrangements with suppliers, the need to take a more holistic view becomes ever more imperative. It may not always be apparent to businesses just how seriously, relatively small changes in their activities will affect other participants in the supply chain. Whereas in the past, this may not have been an overriding concern, this is no longer the case once the decision has been taken to move into single-supplier sourcing with the intention of ensuring a win/win collaborative framework. The supply chain focus may therefore be represented in the re-configured high level modelling view as shown in Figure 9.

In effect this representation involves reengineering processes which cut across the boundaries, not only of internal functional departments, but between organisations. This point can be readily demonstrated using a simple simulation model as discussed below. Supply chain management therefore emerges as a potentially rich area for application of simulation modelling techniques (Evans *et al*., 1995; Towill, 1996; Towill and Naim, 1993).

Simulation's role in business process analysis and change management

From the four core generic business process perspectives outlined above, two salient features emerge. First, operations is absolutely central to all four perspectives. Second, feedbacks, delays and non-linearities exist in each case producing systemic implications which point towards a need for consistent, disciplined, systemic and dynamic approaches to the strategic management of operations in general and business process management in particular.

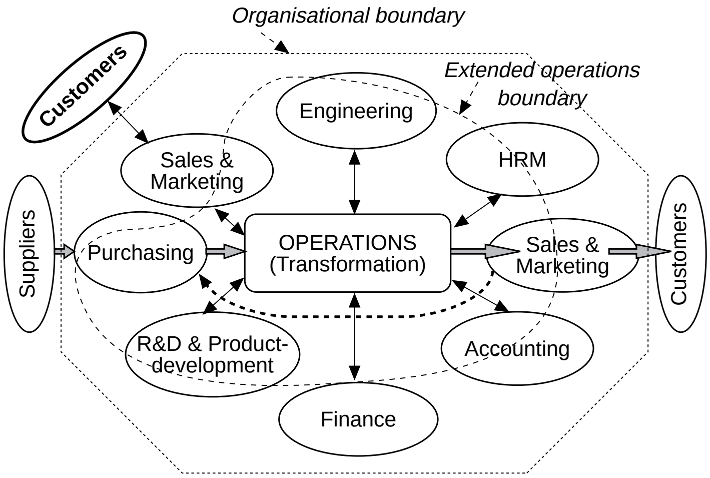

Figure 9.
The supply chain management process

Figure 10 takes this statement a stage further and presents a high-level image of systems theory and simulation's application in change-management and organisational-learning initiatives such as those identified above. In this context BPR is thereby seen as but one member of a family of change management methodologies and should only be adopted after careful consideration (Hammer and Champy, 1993). Hence the logic of Figure 10 assists in making this decision and in planning the corresponding simulation approach.

The preliminary stage involves recognising that a problem exists and then defining exactly what the problem is. In many cases this stage may be much more difficult than is at first apparent. The approach of "soft systems methodology" (Checkland, 1981; Checkland and Scholes, 1990), widely promoted in the literature of information systems development, may play a particularly useful role in this respect.

Following the problem identification phase, the decision as to whether to adopt a TQM or BPR approach bears similarities to the parallel issue of derivative vs innovative methodologies (Harry, 1994), thereby linking BPR once again with the theory of information systems development. The outcome of this decision determines which fork is taken in Figure 10.

If following the TQM branch, the analysis and subsequent modelling focuses on the "as is", observed situation. This is analogous to the derivative approach as improvements are made, which derive directly from the original system.

Conversely, if following the BPR branch then a more radical solution is envisioned. Modelling and simulation will now focus upon the fundamentals inherent in the underpinning "physics" of the system and its business environment and will not be overly concerned with the existing processes and structures. The aim here is to identify new, innovative processes which lead more directly to desired outcomes.

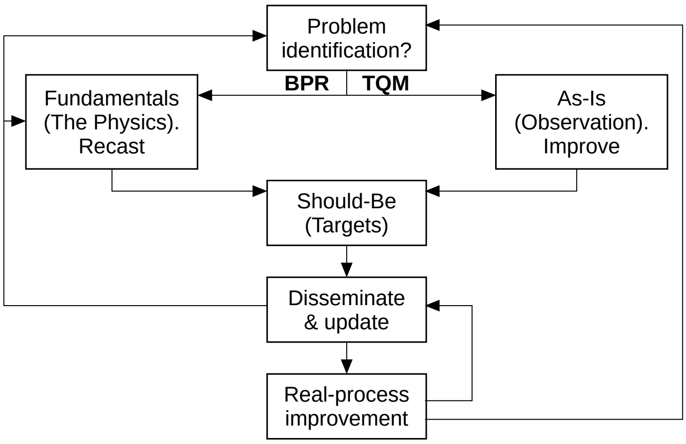

Figure 10.
TQM and BPR simulation

Both approaches ultimately converge again at the stage shown as "should be" or targets (although these will probably be different in content depending on which branch is followed). Results arising from the simulation may then be disseminated to all who are involved in the change initiative. As a result of new information or understanding arising at this stage, further modifications or perceptions of the problem and its proposed solution, might be fed back as shown.

Finally simulation results may be compared with real-world outcomes as the implementation unfolds and feedbacks may be completed either at the lower level, dissemination phase, or at the higher level. This usually implies further problem definition, refinement and some modelling, followed by a further round of experimentation.

Mapping modelling and simulating key management processes

Having decided on a broad change-management approach it remains to define a structured method for modelling and simulating the perceived system. Owing to the generic similarities which exist in systems of different types it becomes possible to postulate a number of core infrastructures which can constitute the basis for adaptation by individual organisations. It is therefore possible to suggest generic approaches to many problems; this may therefore be typified by the seven stage process improvement program given below. This approach underpins many of the simulation products which are available for commercial use (Byrknes and Myrtveit, 1996; Richmond and Peterson, 1990; Spurr *et al.*, 1993; Tampoe and Taylor, 1996; Wolstenholme and Stevenson, 1994):

(1) *Checking objectives.* Vision, strategy and objectives must be consistent and viable before proceeding to design the business processes which will deliver them.

(2) *Business process identification.* Core, sub, and support processes must be individually identified, bearing in mind the generic examples identified earlier in this paper.

(3) *High-level mapping.* Systems-thinking strongly emphasises the interdependence between each of these processes and with the overall system which comprises the environment. These should, in the first instance, be depicted in a high-level map.

(4) *Low-level modelling.* Each process is analysed in terms of its inputs and outputs thereby focusing on discrete but manageable segments of the system, while recognising the existence of interfaces to the adjacent sub-systems. Intuition should be regarded with considerable circumspection at this stage as it can carry a very high risk. The analyst should try to gain a feeling for the dynamic characteristics of each part of the system, with particular reference to, for example, natural frequencies and time constants.

(5) *Deciding on an improvement strategy.* Each process should be considered in turn either for gradual improvement or reengineering. The decision on where to start may typically be answered by asking:

- Which process is currently displaying most dysfunctionality?
- Which offers the best chance of improving overall business performance?
- Which is most amenable to fixing?

It is worth noting that the danger of acting too precipitously in this respect is that in such interacting systems it is notoriously difficult to discriminate cause and effect intuitively. Symptoms often materialise in parts of the system remote from the problem's origin. Also it is rare for radical improvement to result from looking at one process independently as synergy often arises from the interplay between processes. Hence this stage should be approached "without prejudice" and a wide range of options retained for further investigation.

(6) *Experiment.* The simulation provides the basis on which the analyst can test existing designs, make improvements, perform sensitivity analysis and test to the limit to evaluate performance under extreme conditions. Different variations can be explored as far as is considered necessary in order to obtain an optimal outcome.

(7) *Dissemination.* Process knowledge must eventually be disseminated to, and assimilated by, those who will be directly involved in implementation. The process maps, models and graphical outputs associated with simulation enable management teams to gain an holistic perspective rather than a narrow, functional view. Hence information which is presented visually and interactively is more likely to be assimilated and

retained. From such shared understanding it becomes possible to identify and test for further improvements.

Simulation as an aid in reengineering the supply chain

As an illustration of the application of contemporary continuous system simulation techniques, within this particular context, a relatively simple supply-chain model is presented as follows. Supply-chain management involves reengineering business processes across boundaries between internal functional departments and also between independent organisations. The dynamics of such arrangements can be readily investigated using a simple simulation model as depicted in Figure 11. This shows a three stage supply chain in which inventory is aggregated and can accumulate either as finished-stock at the factory, or as work-in progress at either the wholesaler or retailer. Delays associated respectively with production, order processing and delivery transits are shown as intermediate "conveyors". At each stage, stock-monitoring and control feedback-loops are operating to trigger the respective stages of production and despatch in proportion to the discrepancy between target and actual stock levels.

The dynamics of this system, following a sudden 50 per cent increase in the retail customer's order, is shown in Figure 12, which is a classic example of the so-called classic Forrester effect (1958). The retailer's stock initially falls quickly but eventually recovers at a level of 35, down 5 from the original target value of 40. This occurs in a somewhat oscillatory although non-critical way with a generous safety level of stock being retained throughout. The response traces show that these oscillations are also reflected in the wholesaler's stock except that the magnitude is now substantially amplified. Finally, the implication at the factory is seen to be dramatic instability. Significant overshoots and undershoots occur and only the existence of a relatively generous safety stock target level prevents the occurrence of stockout.

Even at this high level of representation it is evident that the simulation can reveal unexpected and potentially counterintuitive behaviours. This allows managers to experiment with different policies and information exchange

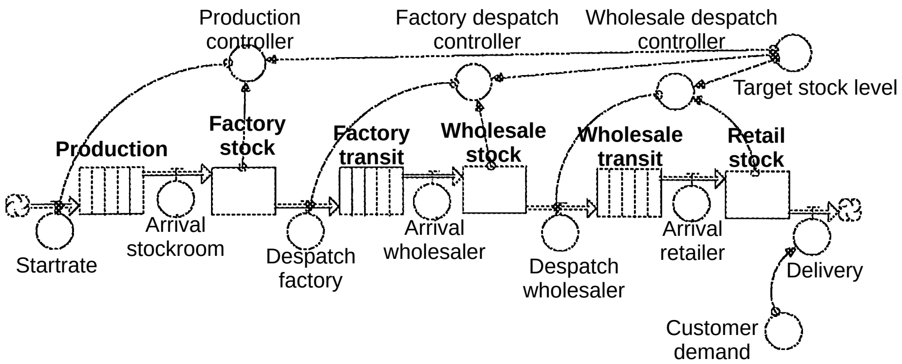

Figure 11. A three-stage supply chain

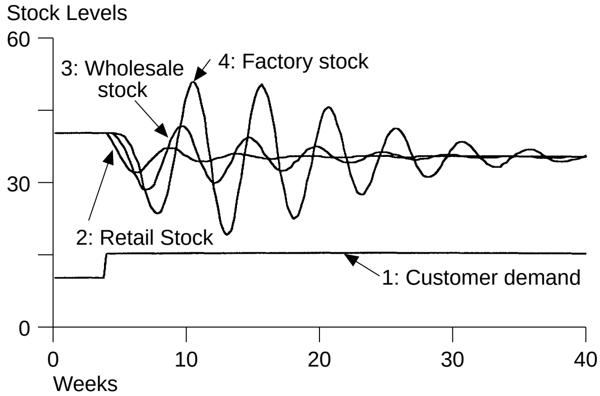

Figure 12.
Typical result from supply chain simulation

flowpaths. For example it may be shown that by feeding forward information from the downstream end of the system, to each of the upstream action nodes, and upon building in intelligent decision criteria at these points, the transient performance of the system may be transformed as illustrated in Figure 13. Elimination of the steady state offset, which is evident with pure proportional feedback control, and which can typically lead to the result depicted in Figure 12, can thereby be achieved by feeding forward the external disturbance to each of the flow controllers in the system. The oscillatory effects can also be eliminated by reducing the gain of the feedback controllers, without unduly retarding response or increasing steady state offset, since this issue has already been addressed by including the feedforward term.

It should also be noted that the physical characteristics of the supply-chain system-model have remained unaltered in this reconfiguration. Improvements have been made simply by reengineering the model's control structure and gain factors. These translate directly into management actions in the real system and point the direction for salutary change in operating policies.

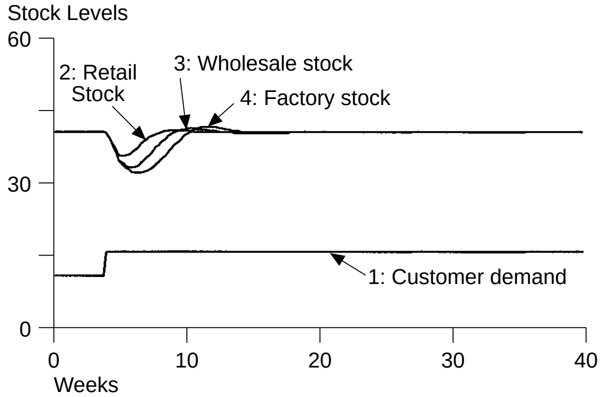

Figure 13.
Typical result from reconfigured supply chain simulation

It may also be possible to produce further improvements using what is, in effect, pure feedforward control, as long as sufficient intelligence is available at the control nodes. A sample model of such a system is presented in Figure 14. It will be apparent that all feedback loops have now been disconnected (i.e. those that actually feedback from the controlled state variable, or stocks to the flow control elements), thereby obviating any possibility of the local dynamic instability that can emerge in feedback systems. The flow controllers f_2, f_3 and f_4 are now programmed by calculations derived from three independent pieces of information as follows:

(1) Each controller must be given warning of primary downstream disturbances (c), as soon they occur, in order to be able to adjust to the new steady-state requirements.

(2) Each controller must have knowledge of the dynamic characteristics of its own stage, e.g. transport delays, depicted here as d_1, d_2 and d_3.

(3) Each controller must be informed of the control condition applying at the next stage immediately downstream which, in turn, determines demand on its own local stage.

A decision must be taken at this point defining the time to be allowed for the adjustment of the "conveyor element" contents to match the new steady state requirements. In the algorithm developed below it is assumed that this period will be set equal to the local delay itself. Hence, if the delay period is two weeks then the time allowed to complete the adjustment is also two weeks. Variations on this policy may, of course, be readily implemented and investigated as required. For example, all conveyors could be required to fill over the same fixed time interval, and this could easily be programmed into the control algorithm.

From this information the controller is able to calculate and algebraically sum together:

(1) The modified flowrate required to accommodate the new steady-state condition derived from "c", the externally applied "system disturbance".

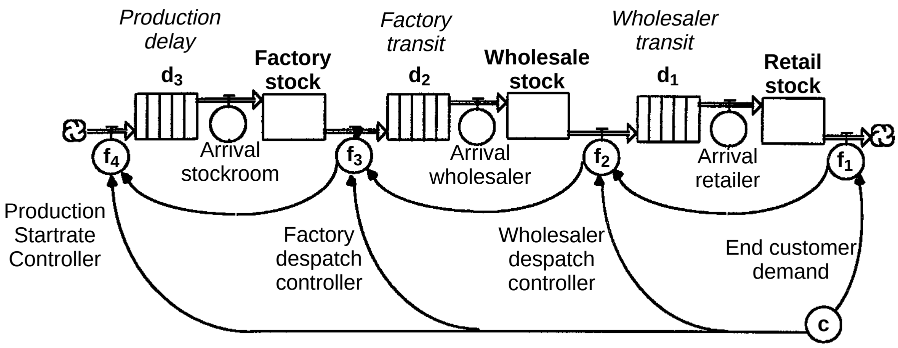

Figure 14.
Intelligent feedforward control

(2) The transient change in flowrate needed to accommodate the readjustment transient in the next element downstream.

(3) The transient change in flowrate required to accommodate the additional filling or draining of the local state-variable (e.g. local stage work in progress) as a result of the change in steady-state throughput.

The flow controller actions may now be specified by the following algorithms:

Disturbance: $f_1 = c = a + a.x(t_1)$

Where "a" is the initial condition and "x" is the normalised percentage change at time t_1.

Hence:

$$f_2 = f_1 + a.x(t_1) - a.x(t_1 + d_1)$$

Similarly:

$$f_3 = f_2 + a.x(t_1) - a.x(t_1 + d_2)$$

and:

$$f_4 = f_3 + a.x(t_1) - a.x(t_1 + d_3)$$

Hence a general pattern emerges whereby:

$$f_n = f_{(n-1)} + a.x(_{t1}) - \text{a.x}(_{t1 + d(n-1)}).$$

The terminology "intelligent feedforward", has been introduced here to distinguish this mode of control from simple feedforward. In the latter case each controller would have been informed of changes in end-customer demand but would not have the detailed knowledge to compute the transient changes listed under items (2) and (3) above.

In the examples of Figures 12 and 13, "x" was 0.5 (50 per cent of the initial condition "a") and the three time delays were equal at one week each. The result obtained when simulating this system under the control of a pure feedforward policy is displayed in Figure 15.

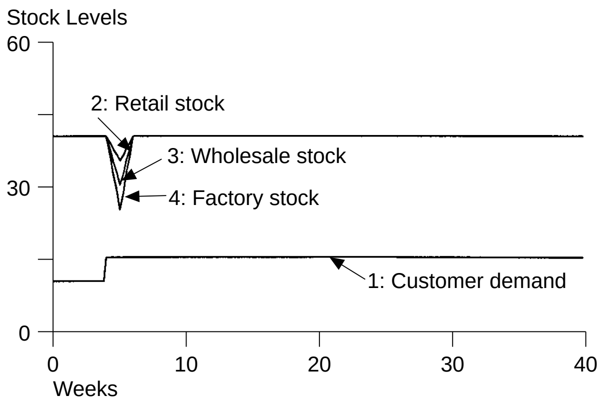

Figure 15.
Transient result with pure feedforward control policy

Recovery, following the step change in demand is very quick and deviations from the target level are minimal compared to those experienced with alternative control options. However, as with the other options, the transient disturbance is still amplified, the further upstream we move from the initial disturbance. In other words the "Forrester effect" is still evident although with reduced magnitude.

Clearly this is a highly idealised response since in practice it is unlikely that the required information would be as crisp and deterministic as has been suggested here. In fact, due to uncertainties and problems of accurately modelling real systems, it is highly unlikely that such perfect information will be available except for very simple cases. However, the example does clearly present the underpinning principles of "intelligent", analytically derived feedforward control, in contrast to the closed-loop feedback mode.

In practice, a combination of feedback and feedforward will probably be required in most real systems, in which case a modified model can readily illustrate and quantify, once again, the underlying inherent dynamics and the various options available for dealing with them.

In summary, the models simulated and interpreted above have been used to demonstrate how managers, who are concerned to establish strategic alliances between respective contributors in the value-system or supply-chain, may be facilitated in the search for appropriate control strategies which will optimise the performance of the whole system, rather than just one part of it. The models are, of course, readily capable of extension into a more sophisticated representation within the context of an actual systems study. Interactivity, causality and transient response are important concepts in BPR and simulation techniques can clearly provide a potentially valuable resource in this respect when evaluating options and exploring potential behaviour.

Multivariable management system mapping

Simple, linear single and cascaded loop models, such as those presented above, may be used very effectively to demonstrate the existence and behaviour of dynamic loops in management systems. However, most organisations consist of a multitude of dynamic loops such as these and are more typically characterised by non-linear and discontinuous functions. Starting with the embedded systemic view expressed in Figures 6 and 7 and emphasising the process orientation which is explicit in BPR it is now possible to propose a high level, partly generic systems model of business as presented in Figure 16. This model is based on the core factors of production which influence the production process and is, in effect, an extension of the classic OM model, sometimes referred to as the 5Ps of operations, featuring product, process, plant, programmes and people (Muhlemann *et al.*, 1992).

Plant considerations include factors such as layout-design, selection of equipment, maintenance, etc. Additionally the availability of plant, quality of facilities, amount of rework required etc. are all factors which affect the actual rate of production.

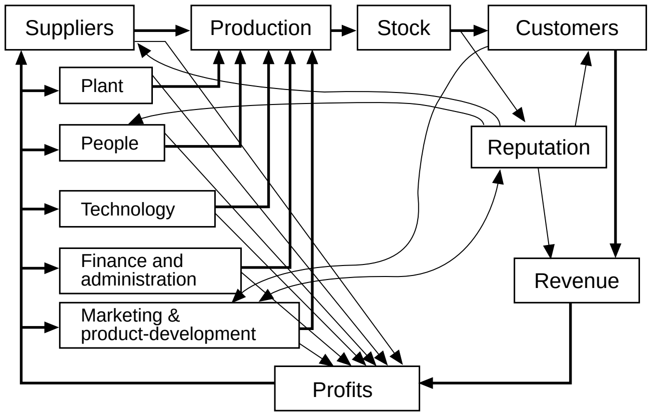

Figure 16.
Multiple feedback structures in production systems

People are also clearly a key factor of production as included in Figure 16. One particular characteristic of the "people model", i.e. the number of staff moving through the system and the number of hours worked, may be readily modelled as state variables within a dynamic sub-system (Fowler, 1996). However, the full implications of the human-resource influence, with respect to production, is obviously much more complex than this and factors such as skill level, degree of commitment and level of motivation must also be incorporated into the modelling process if it is to become more truly representative. This implies introducing soft-variables into the modelling domain, an issue which is briefly addressed later in this paper.

The technology block will typically include computer-aided design and manufacture, developments in robotics, etc. Management needs to be especially vigilant about changes in technology and its impact upon competitiveness. This can occur anywhere in the value-chain affecting any of the primary value processes.

Finance, including the management accounting function, is also clearly a core factor providing the source of funding for the production process and associated budgetary control systems. General administration and information systems management may also be aggregated into this part of the model. This grouping thereby constitutes another important support activity identified in Porter's (1985) classic value chain model.

Finally, depicted in Figure 16 is the core contribution made by marketing, which in this representation is combined with product-development. This could be extended to encompass aspects of the design-function and R&D.

The factors of production outlined above may be considered to constitute core inputs to the fundamental production model (i.e. the process) which in turn gives rise to finished stock, identified here as a prime state-variable. At the output end customers, customer-satisfaction and profitability are clearly identified as the ultimate focus of the system, as is shown in Figure 16.

Revenues are derived from customers in proportion to their number and the volume of trade undertaken with them.

Revenue is a relatively "hard variable" which can be measured directly and can accumulate as a stock-level or state variable as shown. However, other important outputs exist such as reputation, and brand image etc. which although constituting classic "soft variables" may also be thought of, for dynamic modelling purposes, as stocks. These may be deduced as a function of the volume of business passing through the system, and are therefore connected by the corresponding information arrow, to a state variable accumulator labelled reputation.

The respective organisational processes described above have, at this stage, been considered simply as a linear series of subsystems each constituting part of a greater interconnected whole. Realistically, modelling of these subsystems is most readily performed by the respective experts, residing within the corresponding areas, inside the actual organisation. Within this context the generic model of Figure 16 provides a top-down overview which highlights the existence of these interrelationships and possible linking structures. As such it provides a potentially useful starting position. These modelling efforts will probably require some external facilitation by informed expertise and guidance in modelling techniques but it is essential that the models themselves encapsulate the knowledge and understanding of, and be believed by, individuals within the organisation such as members of a BPR team (Morecroft, 1992).

The consequence of closing the loops in Figure 16 has not yet been addressed and clearly, there is much more that can be added to this picture on completing this stage. For example the profit element, which is treated in Figure 16 as another stock "state-variable" or accumulator, invokes continuous algebraic summation of both inputs and outputs. Outflows include payments for all of the core factors of production identified above. This includes payments to suppliers, provision for and maintenance of plant, payment of salaries, provision for training, payment of interest, dividends, taxes etc. and finally the financing of new market initiatives and product development processes. It is noted that inserting these linkages develops the model from a set of linear sequences into a network of multiple closed loops. These, in turn will also have associated delays, any one of which can easily lead to unexpected and undesirable dynamic behaviour which could, in turn, have a disturbing influence on the other loops.

Information links which actually release the flow of funds from the "profit stock" to the various factors of production must also be included, thereby creating additional internal loops. Here again delays and non-linearities can occur, for example in the order-processing and invoicing operations, with corresponding implications for dynamic behaviour.

Finally, a number of additional feedback informational loops may be identified, emanating from the "reputation state-variable" as shown. However, here again processes take time to develop and can be highly non-linear. For example as reputation improves this might generate more customers. Similarly a strong reputation might allow negotiation of preferential treatment by suppliers. It may also impact upon morale in the human resources block making it relatively easier to attract and retain high-calibre staff. Reputation will also influence activities in the marketing section making it relatively easier or harder to attract customers. This is shown here as a two way process as marketing activity should directly influence reputation as well as being influenced by it. Finally reputation may enable the charging of higher prices, per unit despatched, hence the arrow leading to the revenue block.

Another important feedback occurs from the customers to marketing. This will be enacted through market surveys and similar intelligence gathering processes which once again, can invoke significant delays.

In summary, while it is not suggested that the above representation provides a completely generic and totally holistic model of the business system, it does provide a notion of how such a model could be developed at the high level. It also shows the existence of numerous feedbacks and other closed-loops, many of which can contain significant delays and all of which are subject to dynamic behaviour which is defined by the inherent "physics" enshrined therein. Even when viewed as a static entity this representation begins to look somewhat complex. When viewed as a non-linear, multivariable dynamic system, realisation of the potential complexity of the system becomes readily evident. However, the process designer or reengineering practitioner does now, at least potentially, have access to powerful methods and tools with which to proceed within the BPR context.

Ensuring realistic dynamic representation

Notably, when dealing with the softer areas of management, which include "people factors" as well as physical components, additional levels of complexity are encountered. Not least, the equivalents of the deterministic laws which characterise, for example, the natural sciences and engineering, are not available to the social scientist. Hence alternative soft-systems methodologies have evolved in an attempt to establish some form of theoretical basis upon which to build knowledge and understanding (Checkland and Scholes, 1990; Denzin and Lincoln, 1994).

To some extent, these can be introduced into the simulation environment by incorporating stochastic elements into the modelling process, thereby providing a middle ground between the purely deterministic approach and the more qualitative approaches traditionally employed by social scientists and practical managers. It may also be possible in some cases to use non-dimensional scales to represent the state of key variables such as brand-image, morale, and burnout. The introduction of the state-variable labelled reputation, in Figure 16, is a typical example. This can be achieved upon recognising that quantification does not necessarily have to be synonymous with measurability. However, there still clearly exists a need for further research to accommodate the representation and behaviour of such soft system variables and this remains an important and challenging area for further development.

Scoping the system is also a vital consideration. Drawing the scope too widely produces a model which is too extensive and complicated, containing much redundant data which will clutter and possibly crowd-out more meaningful information. Conversely, drawing the boundaries too narrowly can lead to omission of important qualities of the system which consequently devalues the model and may even render its results worthless.

One possible approach is to start locally with a definition of a problem or a concern about a potential problem which may not yet exist but which, it is suspected, might emerge in the future. For example, when contemplating a major change initiative such as BPR, managers may, or should, enquire as to where they see their reengineering efforts ultimately leading? They may start by speculating on what will be the impact of this initiative with respect to the key system variables as identified in Figure 16. It is then necessary to rigorously examine every system output and explore the possibility of feedback linkages to system inputs. Failure to recognise the existence and potential impact of these feedback loops can lead to unforeseen dynamic behaviour which may undermine the long term objectives of a BPR project.

If it is decided that a flow which crosses the existing system boundary is sufficiently important to warrant modelling on the other side, then the boundary (scope) must be expanded to include these factors also. If the inclusion of these additional features becomes sufficiently complicated, then it may be necessary to treat this as another interacting sub-system which can then be modelled separately, thereby further deploying the process of reductionism. By modularising the model-building process in this way the size of the sub-system models remains finite and manageable either by an individual or a small group. Hence different groups could model the various parts of the organisation, with which they are most familiar, developing and building-in their knowledge, without, at this stage, worrying too much about how the implications of activities, in one part of the organisation, impact on those in other sections.

Hence reductionism can realistically be deployed, leaving the modeller to concentrate on one particular domain, safe in the knowledge that the vital consideration of emergent holistic properties of the system will be addressed later at the model synthesis and experimentation stage. This approach probably coincides naturally with the way in which people tend to work anyway, i.e. in the “localist paradigm”. Indeed, this is one of the key problems that is addressed when trying to develop an holistic approach based on simulation methodology. In other words the final stage of synthesis can be deferred until after the sub-models have built and validated.

This process of progressively extending the scope or boundary of the system may continue until a point is eventually reached where there are no more flows crossing the final boundary, i.e. everything that can be recognised as being of significance is now contained within the boundary. Alternatively, some boundary-crossing flows may remain, but can reasonably be designated as "independent variables", i.e. those over which the analyst has no control. These are not simply ignored but are treated as external disturbances which arise in the environment and which impact upon the system. This, in turn, helps define the experimental phase of the simulation study since it helps to identify what needs to be explored, via sensitivity analysis, in order to reveal how the system will respond to a range of suspectedly significant disturbances which might conceivably arise, in the environment.

The prognosis for simulation in management systems

The concepts of system dynamics and simulation, as discussed in this paper, are far from new (Forester, 1958; 1961; 1975; 1995) but a number of trends, currently in train, appear likely to have a dramatic effect on its imminent take up in the domain represented to the right-hand end of the "systems-spectrum" represented in Figure 3. First, there is evidence that perceptions of the concept of process have changed substantially. From its origins as a backroom activity in the operations domain, process is now seen to lie at the core of business activity constituting a highly strategic issue. Second, the emergence of low cost personal computer technology has unleashed an apparently insatiable appetite for end-user computing, thereby providing direct access to computer power even for those with minimal information technology (IT) background. This trend has been matched by parallel developments in software, not least the emergence of user-friendly "front-end"operating systems and GUIs. Within this plethora of software a new generation of simulation products is now appearing and being marketed primarily at business managers (Byrknes and Myrtveit, 1996; Spurr *et al.*, 1993; Tampoe and Taylor, 1996; Wolstenholme and Stevenson, 1994). Exploiting the capability of modern hardware and object-oriented programming these products are accessible, user-friendly and in many cases very realistically priced. Powerful output graphics are available to interpret results and present them in a format which can slot directly into management reports. Most importantly, results can be obtained and information gleaned from raw data, following a relatively brief expenditure of effort in training and familiarisation.

Another consequence arising from the proliferation of the PC is that many younger managers who are well familiarised with and completely at ease with IT, are now progressing into positions of influence within the organisations of the late 1990s. Many will have technological backgrounds and/or MBAs, often featuring MIS and simulation, and these people will be more inclined than their predecessors to experiment with this technique in their planning and decision-making processes.

Finally, there also exists a pronounced trend towards what is termed "the lean organisation" which usually implies downsizing and delayering, often accompanied by the complete elimination of whole tiers of middle-management, leaving a burgeoning requirement for first-hand access to information. Given the nature of the problems which such senior executives face, including strategy formulation, long time-scales and the processing of much unquantifiable data, simulation potentially presents a convenient solution to emerging pressures in a way which is not available via alternative spreadsheet based EIS. In particular, the current emphasis on BPR, with its associated demands for an holistic and systemic approach and an emphasis on business processes which cut horizontally across the full range of vertical departmental functions, further reinforces the need for tools such as simulation.

Conclusions

This paper has argued that systems-thinking and continuous-system simulation potentially provides a highly illuminating framework within which to implement major change initiatives such as BPR. A number of operations oriented models have been presented as a potential basis for this approach and it has been suggested that important advantages can accrue, at several levels, by developing these as a perceptional framework. BPR is ultimately about change in structure and process. However, when undertaking such large, step-change initiatives care must be taken to detect, evaluate and accommodate dynamic, as well as equilibrium, phenomena. Organisational learning should become a prime objective in this respect and the powerful contribution made during the qualitative modelling phase of a simulation study is clearly emphasised within this context. Having to explain clearly and unambiguously to colleagues, through the medium of team based, qualitative system mapping and modelling activity, how we think the system works, can prove to be a powerful aid to organisational learning. Programming and quantitatively representing the system builds on this understanding leading ultimately to a state of "informed anticipation" or foresight, in the final analysis, on scrutiny of the simulated predictions.

The redesigned processes and their associated controls (policies) may then be safely evaluated, free from the risks associated with implementation and experimentation on the real system. Any problems inherent with proposals for redesigning systems can thereby be evaluated, in safety and at relatively modest cost. Managers are thereby able to gain a preview of the likely effects which their re-engineered structures and policies can be expected to achieve. Such an exercise can prove highly revealing and a central purpose of this paper is to convey this message to practical managers who may not previously have considered this particular application of simulation technology.

Hence the paper has argued that there currently exists an unprecedented need and opportunity for exploitation of systems thinking and continuous simulation methodology in OM, strategy and BPR. Current enabling factors include software availability, changes in management thinking and a BPR inspired predisposition towards process orientation and exploitation of IT. It is suggested that tools which have traditionally been seen as appropriate only for engineering and the "hard-sciences" will increasingly find applications in "softer areas" such as management. Similarly it has been argued that many of the tools of control theorists may, in adapted form, also begin to be perceived as potentially useful in policy formulation and organisational design.

Finally, it has been shown that core business processes such as product-delivery, product development, staff recruitment, retention and development, customer acquisition and strategy formulation, may all be viewed as interacting, closed-loop, dynamic sub-systems, collectively possessing distinctly complex characteristics. A high level architecture for mapping these processes has therefore been suggested as a generic framework, capable of adaptation for modelling particular organisational systems.

In summary, it has been argued that the simulation approach potentially offers to senior managers, the opportunity to benefit from powerful learning experiences and improved decision making processes when undertaking major change initiatives such as BPR. Such a methodology, especially when used in a group learning, customer focused environment, can provide an invaluable aid in revealing dynamic organisational interdependencies. Often these can, in turn, be reshaped to promote a more proactive, market driven culture. Furthermore, through the facility of scenario planning and quantitative evaluation, managers are potentially enabled to develop a high degree of confidence with regard to the likelihood of success, during the implementation phase of their change management initiatives.

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