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Algorithmic Framework for Business Process Innovation*

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Abstract

Various organizational factors effect successful implementation of IT enabled business transformation. Among them, the most critical success factor is deemed to overcoming change management problem. Lots of studies have been made on implementation methodologies and business process formalizations to encourage organizational members to accept new business process changes. However, the logic of process redesign still depends on qualitative problem solving techniques mostly depending on basically human intuition such as brainstorming, cause-and-effect analysis, and so on. In this paper, we focused on developing analytic framework to design to-be business process structure, which can complement qualitative problem solving procedures. With effective use of IT as an enabler, we provide algorithmic framework applicable to designing various business process changes such as process automation, business process resequencing, and more radical process integration. The framework follows dynamic programming approach in the literature, which is based on the decision making paradigm of organizations to abstract business processes as quantitative decision models. As such, our research can fill the gap of limited development of theory based analytic methodologies for business process design, by providing objective rationale to reach the consensus among the organizational members including senior management.

Key words : Business Process Design, Change Management, Decision Model, Quantitative Analysis, Dynamic Programming

1. Introduction

One of the most significant efforts in the 1990's to capture competitiveness using IT is business process engineering. With the rapid propagation of internet and information technologies on the web, the scope of business process redesign has been expanded across firms from the internal business process optimization to enhance the firm's productivity and customer services [11]. The importance of business transformation as an extended enterprise has been addressed earlier [10][25], and internet expedites expanding the scope of process change to across the firms on the supply chain [4][23]. Still, the practical usefulness of business process perspective and change management concept appears unassailable [12][17][42][46].

However, as was reported that 70 percent of BPR projects failed [15][46], the effective use of IT as well as rational process redesign is still a challenging subject. Various organizational factors effect successful implementation of IT enabled business transformation [6][16][24][40]. Among them, the most critical success factor is deemed to overcoming change management problem that is defined as "potential problems due to failure to manage change from the old process to the new process" [14][15]. The core of change management lies in getting consensus on to-be model from the organizational members. Resistance to changes will necessarily occur since process oriented business transformation restructure more familiar as-is organizational practices [37].

To encourage organizational members to accept new business process changes, practical change management techniques are widely used. Lots of studies have been made on implementation methodologies and business process formalizations [24][46]. Process modeling tools are widely used to figure out as-is business structure and to-be design alternatives. Petri-Net [1], Architecture of Integrated Information Systems (ARIS) [13][41], and other systematic process modeling techniques [8][31][38] are prevalent for effective process modeling. They are effective to allow sharing and evaluating the alternatives to relevant organization members by pictorially demonstrating the to-be process. However, the logic of process redesign

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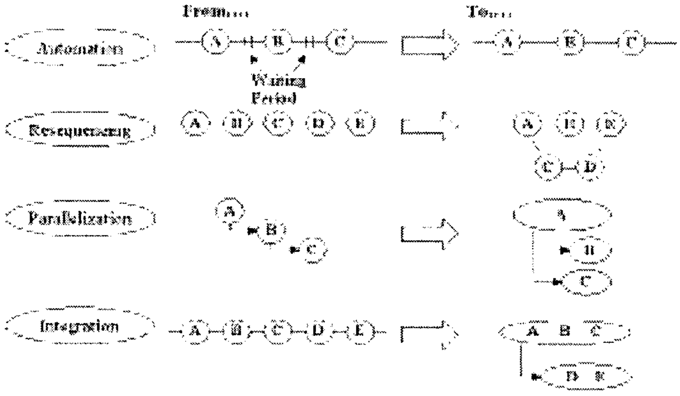

Figure 1. Business process change patterns

still depends on qualitative problem solving techniques mostly depending on basically human intuition such as brainstorming, cause-and-effect diagram analysis, and so on [39]. Compared to extensive empirical studies concentrated on the behavioral aspects of BPR implementation, development of theory based analytic framework for business process design has been limited [19][33][34]. In this paper, we focused on developing algorithmic framework to design to-be business process structure, which can complement qualitative problem solving procedures. As such, our research can fill this gap of limited development of analytic methodologies. Quantitative model to design and evaluate to-be process alternatives can help overcoming change management problem by providing objective rationale to reach the consensus among the organizational members including senior management.

In section 2, we analyze business process change patterns and explain the benefits and IT implementation focuses. Along with general discussion on quantitative approach to business process design, decision model based approaches [36] is outlined in section 3. In the next section 4, dynamic programming based algorithmic development of process redesign is illustrated, which is based on Orman's framework introduced in section 3. Implications on the application potentials of our algorithmic framework to various business process changes are suggested in section 5. The limitations and further research directions are discussed in section 6.

2. IT enabled business process change patterns

In the early days of IT implementation, cost reduction from automating activities is the most significant IT effects on organizations. One of the rudimentary benefits from implementing information systems is to reduce man-hour cost by automating routine work or eliminating non-value adding activities. Resistance to changes will be minimal if process change level is simple automation without restructuring business process. For more effective use of IT as a means to strengthen competitiveness, more radical business process changes are sought in BPR. As illustrated in figure 1, patterns of business process change can be categorized as simple automation for process streamlining, linear resequencing, resequencing involving process parallelization, and more radical process integration.

While process streamlining aims at improving process efficiency from IT contribution to reduce less value adding work and waiting time between processes, business process resequencing exploits the advantages of reducing decision making efforts required to perform the task by the introduction of IT. Since IT effects process cost changes measured in terms of uncertainty reduction, resequencing the process order in addition to process streamlining can reduce total process cost and lead time. By resequencing the task processing order of the process chain, the advantages of reducing process cost from computerization of a particular business process can be fully exploited [36]. Further alternative is to add parallelization option in addition to linear resequencing of tasks. The industrial applications of cycle time reduction through parallelization are manifold.

For instance, concurrent processing of planning activities among supplier, manufacturer, and distributors by process parallelization can reduce supply chain cycle time from raw material conversion to finished goods, and selling through distributor [26].

Similarly, total lead time for new product can be radically shortened by parallelizing new product development processes among the firms, which were carried out sequentially and subsequently linked after the pre-processes are completed [23]. As an enabler to concurrent processing, web based information technologies play a crucial role to allow information sharing among them. Figure 2 illustrates concurrent processing of new product development using web based information technologies.

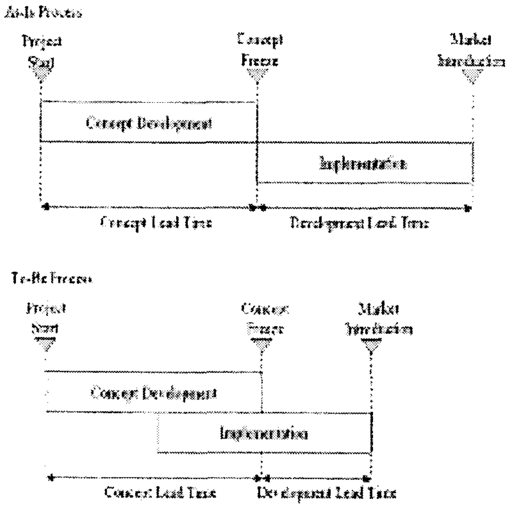

Figure 2. Business process parallelization example [23]

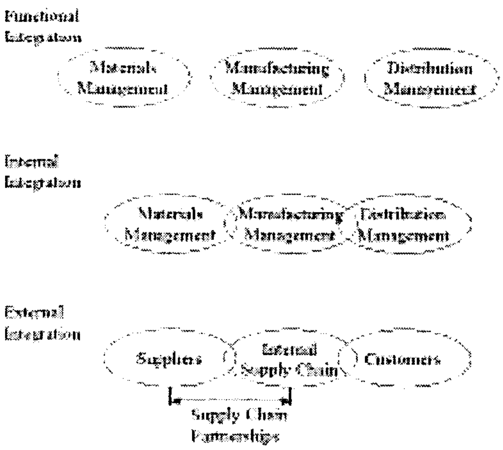

Figure 3. Business process integration stages [30]

Business process integration affecting organizational structure is more complicated issue. From decision aspects of the organization process, it seeks global optimal through aggregating local processes which runs in local optimal status due to the separation. For example, integrated single organizational unit can manage both production planning and sales planning to overcome functional optimization perspective. The effective use of decision support systems can support business process' integration. As was suggested by and quoted in figure 3, the business process integration evolves from functional integration to interface integration usually for coordinating trade-off goals among functional departments, and more extended business units across the supply chain. Business process change patterns and associated IT usages for performance improvement focuses are summarized in Table 1.

3. Fundamental analytic framework

The advantage of quantitative approaches is in modeling capability to analyze the business operations systematically, and evaluating the effect of business process change. Computer simulation techniques and mathematical programming based algorithmic approaches are attempted to find the optimal business process structure [4][12][19][27][36][45]. While mathematical programming techniques have difficulty in incorporating behavioral aspects of business process, decision making process based analytic approaches are well suited in performance appraisal of organizational structure alternatives, organizational design, information and decision support systems design [2][13][21][22][28][29][35].

Based on the decision making paradigm of organizations [20][43], business processes are abstracted to quantitative decision models. Business process sequencing and restructuring organizational hierarchy problems are examined in light of reducing total cost of implementing decision tasks. Though this approach cannot sufficiently reflect strategic value aspects of process, it is effective as a process redesign rationale for IT intensive business transformation. Decision model based view of process can reflect the advantage of efficiencies created by information technologies. Our algorithmic framework is based on decision making paradigm of organizations, and suggests algorithmic procedures of Orman's model management approach [36]. Overall outline of Orman's model management approach to BPR is summarized as follows.

Table 1. Business process change focus

Pattern	Change focus
Simple automation	• Streamlining process to eliminate less value adding work and process redundancy • Rudimentary benefit from system integration
Resequencing	• Evolved from business process automation • Effected by process cost reduction from IT implementation • More radical process change than simple automation
Process parallelization	• More effective to cycle time reduction • Applicable to business process expansion such as supply chain synchronization, new product development • Web based IT utilization for information sharing
Process integration	• Considering benefit from local optimal to global optimal: e.g. sales and production integration • Usually requires rigorous decision support system development

Viewing the firm as a sequence of decision process, business processes are interpreted as collection of decision models. A decision model is a construct that transforms input data into a specific decision that satisfies the constraints of the model. Each decision task t_i is characterized by two parameters, the cost c_i, and the selectivity s^v_i for each input variable v of task i. The cost of a task is intuitively defined as the resources used to execute the task, such as the value of the decision maker's time for a special decision task. Formally the cost of a decision making is defined by the complexity of the implementing algorithm, which is a function of the size of its input variables. Selectivity is defined as the remaining search space after the execution of the task as a percentage of the initial search space or alternatively $1 - r_i$, where r_i means the percent reduction in search space affected by the execution of the task. This model management approach does not require a utility function, which is a major advantage since utility functions are notoriously difficult to obtain and verify.

A model T with tasks $t_1, t_2, \ldots, t_n$ is given. Each t_i has a complexity function c_i, and selectivity s_i. The selectivity s_i is defined as $1 - r_i$. A single model problem is to find the optimum sequence of execution for the tasks $t_1, t_2, \ldots, t_n$ to minimize the cost of information processing. This problem is a special case of the sequential decision making problem [32] and can be formulated as a dynamic programming problem as follows.

$$f(T_i) = MIN_{t_p \in T - T_i} \; (\Pi\, s_i)\, t_p \;+\; f(T_i \cup t_p)$$

The objective is to find the optimum cost $f(\Phi)$ where $f(T) = 0$ and Φ is the null set. Intuitively $f(T_i)$ represents the optimum cost of the partial model $T - T_i$, that is, the minimum remaining cost after the execution of the tasks T_i. It is equal to the cost of the next task t_p+ the minimum remaining cost after the execution of the task after $T_i \cup t_p$. The critical problem in BPR is one of structure, and the problem is computationally solvable with complexity of $O(n!)$. Considerable computational simplification is possible since some tasks in every process are fixed in sequence because of input-output relationships with other task. This dynamic programming formulation yields reoptimized business process sequences to reflect the process cost reductions after information technology implementation.

4. Algorithmic development

The optimal cost $f^*(T)$ and processing order of task T can be obtained through enumeration by exploiting computational gain captured from optimal substructure of dynamic programming [7]. For ease of explanation, we use the term "level" as the distance from the root node instead of height from leaves. At level 1, each single task is associated with each node, so that no computation is required and the cost and selectivity is stored. As the tree expands downwards, the number of tasks examined for optimal sequencing are increased one by one. For each node at level 1, descendant nodes is generated by adding tasks not considered at the parent node. For example, from the node corresponding to task index 1, descendant nodes of (1,2), (1,3), ,, (1,n) are generated. At level h, each node examines optimal sequencing of tasks consisting of h tasks. In order to avoid redundancy in examining the sequencing permutations, simple rule is applied in generating descendant nodes from a parent node. Assume that nodes at level 1 is created in sequential ascending order of tasks 1, 2,,, n, from left to right. Then descendant nodes at level 2 from r^{th} node of level 1 consists of nodes which examines combination of (r, j) where task $j \geq r+1$ and $j \leq n$, which avoids reexamining (j, r) at j^{th} node for task $j \geq r+1$. Using this rule, the number of descendant nodes from r^{th} node at level 1 becomes $(n-r)$ and no descendant node is generated from n^{th} node, so that the total number of nodes at level 2 becomes ${}_nC_2$. The height of enumeration tree is n and the total number of nodes at level h is ${}_nC_h$. Hence, the total number of nodes in the enumeration tree becomes ${}_nC_1 + {}_nC_2 + {}_nC_3, \ldots + {}_nC_n = 2^n - 1$. The entire node traversal can be done in less than 2^n steps. As an example, the enumeration tree with the task index set {1,2,3,4,5} is illustrated in figure 4.

In general, the r^{th} node at level h examines optimal sequencing for the set of tasks $P^h_r = \{p_1, p_2, , , p_m\} \subseteq T$, which represents index set of partial tasks extracted from T. Without loss of generality, we assume p_m is the new task index added at the present r^{th} node at level h branched from parent node where optimal sequence with $\{p_1, p_2, ,, p_{m-1}\}$ is retained. At present node, the optimal sequence for the set of tasks $P^h_r = \{p_1, p_2, ,, p_m\}$ can be obtained by exploiting the computational result from the previous nodes at level h–1 or less than that. To reuse the computation result from the previous nodes, enumeration tree traversal shall be made in width first order. The optimal sequencing of P^h_r is sought through m+1 times of comparison for all the cases from positioning p_m prior to p_1, next at between p_1 and p_2 , between p_2 and p_3 , subsequently up to positioning after p_{m-1}. At q^{th} comparison, by intruding p_m to q^{th} position of the optimal parent node sequence $\{p_1, p_2, ,, p_{m-1}\}$, the set is divided three components, $\{p_1, p_2, ,, p_{q-1}\}$, $\{p_q\}$, $\{p_{q+1}, p_{q+2}, ,, p_{m-1}\}$, where $p_q = p_m$. The computational gain comes from reusing the optimal cost of $\{p_1, p_2, ,, p_{q-1}\}$ and $\{p_{q+1}, p_{q+2}, ,, p_{m-1}\}$ from the node at level q-1 and m-1-k each respectively. The optimal sequences for the subset $\{p_1, p_2, ,, p_{q-1}\}$ and $\{p_{q+1}, p_{q+2}, ,, p_{m-1}\}$ will be retained, that is principle of optimality is applicable from optimal substructure. We define optimal cost and corresponding selectivity as $R^*(p_1, p_2, ,, p_{q-1})$, and $Q^*(p_1, p_2, ,, p_{q-1})$ each respectively for the given set of tasks $\{p_1, p_2, ,, p_{q-1}\}$. At q^{th} comparison, we can compare only the minimum of two sequencing alternative, the one is $\{p_1, p_2, ,, p_{q-1}\}$, $\{p_q\}$, $\{p_{q+1}, p_{q+2}, ,, p_{m-1}\}$, and the other is $\{p_{q+1}, p_{q+2}, ,, p_{m-1}\}$, $\{p_q\}$, $\{p_1, p_2, ,, p_{q-1}\}$. The total cost of former sequencing, which we define as $R_+^*(q)$, is calculated as $R^*(p_1, p_2, ,, p_{q-1}) + Q^*(p_1, p_2, ,, p_{q-1}) \times s_m \times \{c_m + R^*(p_{q+1}, p_{q+2}, ,, p_{m-1})\}$, where $q = m$. In the same way, $R_-^*(q)$, the latter sequencing cost can be calculated. Using our notations defined above, finding optimal sequence of $P^h_r = \{p_1, p_2, ,, p_m\}$ at the r^{th} node at level h is summarized as the following formula.

$$R^*(p_1, p_2, ,, p_m) = Minimum_{q=1,2,,m}\,(R_+^*(q),\ \ R_-^*(q))$$

$Q^*(p_1, p_2, ,, p_m)$ is obtained simultaneously when $R^*(p_1, p_2, ,, p_m)$ is calculated using the formula. We note that the optimal solution is found at the first node at level n. Following procedure RESEQUENCE (T) algorithmically summarizes our enumeration based dynamic programming solution finding process for the given task set T. Procedure RESEQUENCE traverses maximal 2^n number of nodes, and maximal n times of comparisons are performed at each node. So that the procedure returns optimal process redesign solution in $O(n2^n)$, which is much less than $O(n!)$ of n^n computational complexity suggested by Orman. Considerable amount of infeasible process sequencing will prevents exponential increase of computation so that the algorithm can track optimal solution in a reasonable time.

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Procedure RESEQUENCE (T)
  Do  i=1, n   R*(i) ← c_i;   Q*(i) ← s_i;
  Do  h = 1, n
    Do l=1, nC_h
      u ← max |p_i|   where p_i ∈ P^h_l
      Do  j = u+1, n
        r ← l + 1;   m ← j
        Update P^h_r ← P^h_r  ∪  {m}
        Calculate Q*(P^h_r), R*(P^h_r) from Minimum
            q=1,2,,m ( R+*(q),  R-*(q) )
  f*(T) ← R*(P^h_r)
  Return (f*(T))
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5. Application potential to process innovation

Potential applicability of decision model perspective and resequencing algorithm are manifold for business process innovation. The primary advantages of adopting quantitative algorithmic framework lies in quantitatively measuring change alternatives in light of performance target achievements. Business performance targets are usually defined quantitatively with respect to internal efficiency and market performance, and affect to-be design as business process change imperatives. The practical importance of measurement driven business process reengineering has been emphasized in many literature [34]. Quantified gains from performance improvement can be compared with IT investment cost. The difference of the optimal cost $f^*(T)$ with the total process cost of the as-is procedure can be interpreted as the value IT investment. In general, firms conceive alternative IT deployment options and evaluate with respect to level of process changes and gains. Therefore, for various IT investment options with cost V_k for $k=1, 2, .., K$, each optimal process cost $f_k^*(T)$ can be compared. That is, the optimal IT investment decision can be obtained from $Minimum_{k=1,2,3,..,K} \{ f_k^*(T) + V_k \}$. As such by extending the algorithmic framework, instead of redesigning after the introduction of IT, it can be used to find business process redesign solution that enables achieving predefined performance target.

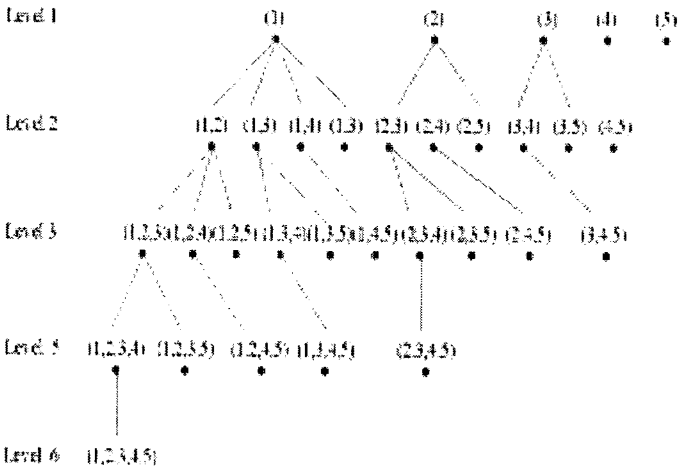

Figure 4. Enumeration tree example

The framework can be modified to include parallel processing and resequencing. Cycle time reduction has been regarded as one of the critical performance improvement target for general IT intensive business process innovation projects. Since parallel processing of business processes usually requires more information supported by rigorous information technology implementation, we expect that IT cost also increases as the lead time reduction target gets more tight. The practical application of the framework to find business process structure including concurrent processing options are addressed in other place [18]. Business process integration is distinguished from concurrent processing in the sense of exponentially increasing complexity. Since decision model perspective of organization explains task units are designed to manage the uncertainty within the tolerance limit of human information processing and efficiencies from specialization of repetitive work, integrating sequential or parallel processes will cause rapid increase in processing cost. Therefore the analytic model to show integration mechanism requires including strategic performance associated with physical processes to compare the gains from global optimality and the information processing cost to cope with exponential growth of complexity for reducing uncertainty.

6. Conclusion

In this paper, we organized business process change patterns and illustrated algorithmic procedure that can be applicable to designing them. The algorithmic development is dynamic programming approach suggested by Orman's, which is based on decision model based theory of the firm. The enumeration can track the optimal structural alternative in the computational order of $O(n2^n)$, which is much less than $O(n!)$ of n^n computational complexity conceptually suggested by Orman. Application potentials are suggested in light of target driven process innovations, evaluating the value of IT investment alternatives, and more complicated process design options such as process parallelization and integration. As such research extension areas will include rigorous development of the application potentials addressed in section 5. Similar to other information processing cost based organizational design models, our framework has limitations in reflecting value aspects of business process. Therefore another research extension area can be suggested as to develop more comprehensive framework by incorporating multiple goals, and linking business processes with physical processes.

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