Workflow Optimization through Task Redesign in Business Information Processes

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Abstract

The academic and professional literature addressing business process reengineering points at inter-task information flow delays (handoffs) as a major source of processing errors and excessive delays in job completion times. Many of the success stories cited in the literature call for employee-empowerment and task consolidation. It means that many benefits are accrued by consolidating tasks, rather than processing the existing task structure at a faster rate. However, there has not been any systematic methodology available to determine the optimal re-bundling of information intensive tasks. Our paper presents a new powerful methodology designed to optimally consolidate tasks in order to reduce the overall cycle time. This methodology takes into account the following parameters: precedence of information flows, loss of specialization, alignment of decision rights, reduction in handoffs and technology support costs. Several application examples presented here highlight the viability of our approach and illustrate the key organizational and technological tradeoffs associated with the redesign of transaction processing activities.

1 Introduction

The famous IBM Credit case discussed by Hammer in [13], points at an example where the average cycle time for the credit approval process was 6 days while the total time spent in performing the tasks was only 90 minutes. This is typical of transaction processing environments such as accounts payable, claims processing, etc., where most of the cycle time is taken up by inter-task handoff delays. An obvious way of reducing the over all cycle time is simply to combine multiple tasks into one. This results in fewer handoffs.

Combining tasks usually incur costs through loss of specialization, loss of control, and other factors discussed later. These costs depend on the tasks being consolidated, on the skill level needed for each task, and on the technological support.

Information technologies have dramatically changed the cost of transferring information both up and down the organization [3],[4],[17], and [19]. A direct consequence is that the current division of labor and division of management is no longer efficient. To deal with this problem, principles such as "organize around outcomes," "link parallel tasks," and others are proposed to guide BPR efforts by Hammer in [12]. However, these heuristics may not always result in positive net benefit. Industry practices have indicated that trying to apply these rules to the whole organization is one of the major reasons why many reengineering efforts failed [11]. Controlling the scope and the time-span of reengineering efforts is very crucial to their success [14]. Early analysis of these rules focused on the queuing effects of various job designs [5]. Very few studies have aimed at developing methodologies for dealing with business processes that are comprised of dozens of tasks with complex information precedence requirements. Our methodology differs from the Project Evaluation and Review Technique (PERT) and Critical Path Method (CPM) approaches as we seek to change the information precedence and the overall process network topology through task consolidation. Since, not performing any consolidation is feasible in our framework, we can view our methodology as an extension of the conventional PERT/CPM approaches.

From a workflow point of view, redesign initiatives for a given business process are commonly achieved through bundling of jobs, or consolidation of tasks [2]. For example, reduced control represents combining the processing task and the controlling task so that the same person is responsible for both tasks. Employee empowerment is the practice of giving the employee who gathers information the authority to make decisions based on that information, which can also be thought of as consolidating the task of decision making into the task of information gathering. Replacing specialists with generalists is equivalent to consolidating multiple tasks into one.

Redesigning the workflow of an organization is as complex as the organizations are varied. The most basic

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constraints that we have to address are the precedence constraints between tasks that arise from information flow or other physical workflow reasons. Any feasible workflow has to create a schedule that satisfies these information precedence constraints. The key contribution of this paper is that we consider task redesign through consolidation to expand the set of feasible choices while still satisfying the constraints. While task consolidation is the focus of this paper, we stress that a number of other factors, not explicitly modeled in this paper, also affect task design. These range from the stochastic nature of the workload, human resource considerations of skills and availability, to informal responsibilities of a worker, such as answering phone calls that interrupt the worker.

The objective of our paper is to present a practical methodology for identifying profit-maximizing changes in the structure of complex administrative processes. We propose an efficient task consolidation approach to combine multiple tasks in a process network. Consolidation of tasks may reduce or even eliminate losses and delays due to inter-task communication and handoffs. Such changes must be done with caution as they may result in delegating decision rights to the wrong person (from e.g., not having specific information), and lead to increasing agency costs (from e.g., reducing checks and control). It may also increase the cost of a decision by reducing productivity gains from specialization or by not utilizing human resources in the most efficient way (e.g., requiring employees with higher skills to do work that requires lower skills). Reduced communication and inter-task communication has two implications. First the cost of communication may be reduced. Second, the delay between tasks will be shortened or eliminated. However, since a process usually spans over multiple functions, it may or may not improve the total cycle time of a process. In some cases, it may even worsen the cycle time. Technology, especially Electronic Document Management plays a big role [20]. In a companion paper in this volume, [8], we examine electronic document technology to aid in task consolidation. In our earlier work, [9] we studied the task consolidation problem for sequential document flow processes. In this paper, we extend it to general networks and provide a mathematical model that is applicable to process with, both, sequential and parallel workflows.

Our task consolidation approach is most applicable to administrative processes with relatively stable task structures such as order fulfillment by mail order distributors, mortgage processing, medical billing, or configuration management in large scale engineering design projects. Our model also assumes that the delays between two tasks are also relatively fixed. Routine transactional processes, such as order fulfillment or accounts payable, usually fit these assumptions. Future work will deal with more complex scenarios, in which both task times and delays are random variables.

The rest of the paper proceeds as follows: Section 2 introduces the general mathematical model of consolidation. The impact of organizational characteristics on the technology and workflow chosen in explored in Section 3. A summary of results are presented in Section 4 and our conclusions are in Section 5. Appendix A provides a summary of notations used. Appendix B presents the formulation for process networks.

2 Task Redesign

Consider the business information flow process, described in Figure 1. This process requires four tasks and has three precedence constraints. Each one of these constraints represents information flowing from an upstream to a downstream task (handoff).

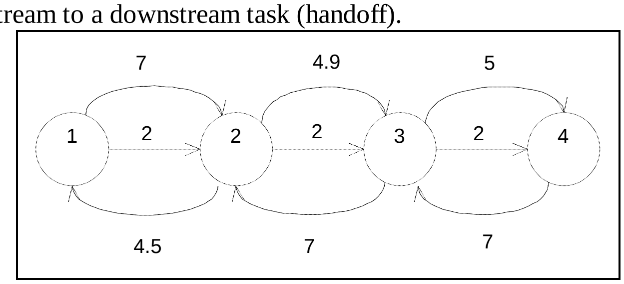
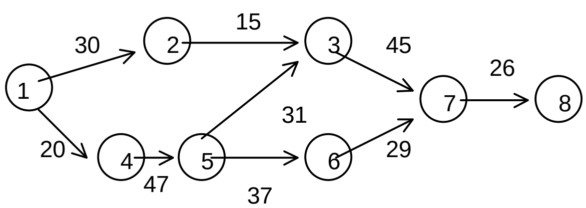


Figure 1: A sequential process with four tasks.
Nodes respresent tasks.
Straight arcs represent information flow and handoff delay.
Curved arcs show the consolidation cost.

This example assumes that all task times are 1 hour and that the handoff delay between any two tasks is 2 days. As mentioned in the introduction, this disparity in task times and delays is common. For instance in the IBM Credit case discussed in [13], the cycle time for the process was an average of 6 days while the total time spent in performing the tasks was only 90 minutes. The total cycle time is then 6 days and 4 hours.
Clearly, most of the cycle time is composed of inter-task handoff delays. The most obvious way of reducing the over all cycle time is simply to combine multiple tasks into one. This results in fewer handoffs. For example, if task 1 and task 2 are combined, the cycle time is reduced to 4 days plus 4 hours, a 32% reduction.

Combining tasks usually incur costs through loss of specialization, loss of control, and other factors discussed later. These costs depend on the tasks being consolidated, on the skill level needed for each task, and on the technological support. If the cost of consolidating task 1 into task 2 is $7,000 over a specific planning time horizon, and the cost of consolidating task 2 into task 1 is $4,500, then applying the latter consolidation is preferred over the former. Costs related to all pair-wise consolidations are represented on the directed arcs shown in Figure 1. Assume that the value of reducing the cycle time by 1 day is $3,000. The optimal consolidation pattern for this process is to consolidate task 2 into task 1, and to consolidate task 3 into task 4. Note that tasks 2 and 3 are not consolidated, although consolidating task 2 into task 3 seems to be a valid solution. This is because once task 2 is consolidated into task 1 by letting task 1 do all the work previously done by task 2, the option of letting task 3 do all the work previously done by task 2 is no longer a viable option.

Now consider an administrative process with more general workflows.



Task	1	2	3	4	5	6	7	8
Processing Duration (hours)	2	5	7	3	1	8	2	4

Figure 2: Business Process with general information flows.

Tasks are represented by nodes.
Information flows are represented by arcs.
Consolidation cost is the weight on the arc.
Table provides the task time

The process depicted in Figure 2 consists of 8 tasks and nine precedence constraints. Each task takes certain amount of time to finish that is listed in the table in Figure 2.

Handoff delays are incurred when there is an information flow from the upstream task to the downstream task. In this example, there are handoff delays from 1 to 2, 1 to 4, 2 to 3, etc. We assume that the handoff delays between any two tasks are 3 hours. The consolidation costs (in thousands of dollars) are represented numerically on each arc. The critical path of this process is 1→4→5→6→7→8. The cycle-time of this process is 35, of which 15 units are due to handoff delays between tasks.

Consolidating tasks reduce handoff delays, thus may improve the cycle-time. For example, consolidating tasks 7 and 8 would reduce the cycle-time from 35 to 32. However, consolidating 3 and 5 would prolong the total cycle-time from 35 to 44. This is because, due to this consolidation, task 6 cannot start until task 3 has finished, since 3 and 5 are combined into one task. Only certain consolidations are possible. For example, task 1 cannot be consolidated into task 5 without consolidating 4 and 5 also. If 2 is already consolidated into 1, 2 cannot at the same time be consolidated into 3. Pair-wise consolidations can represent consolidation of more than two tasks. For example, consolidating tasks 6, 7, 8 can be represented as consolidating tasks 6 and 7 and tasks 7 and 8.

Consolidating two tasks would usually incur costs as well as cause loss of specialization. Which tasks to consolidate depends on the organization's willingness to manage change and the importance of cycle time reduction. Next, we present a mathematical model that captures the tradeoff between the benefits and costs of task consolidation.

Let n be the number of tasks in a process network. Let i, j be indices for this set of tasks. The process network can be represented by a directed graph $G(V, E)$. Nodes in set V represent tasks. Each directed arc in set E, from i to j represents a precedence relationship, which states that j cannot start until i has already been completed. Assume that the process forms an acyclic directed graph and that there are no redundant arcs. This is reasonable since the model in our paper is based on information requirements. In such a setting, cycles are commonly associated with control and feedback processes. We focus on the primary task rather than control processes and hence we consider only acyclic graphs. We define tasks i and j to be *neighboring tasks* if there is a directed arc from one to the other. Let the input binary parameter a_{ij} be 1 if there is a directed arc from i to j, and 0 otherwise. Let the input real-valued parameter τ_i represent the processing time of task i (minutes). Let the real-valued parameter γ_{ij} be the hand-off delay between i and j when there is a directed arc from i to j (minutes). Consolidating i and j is assumed to eliminate this delay.

Define decision variables $f_1, f_2, f_3, \ldots f_i, \ldots f_n$ to be the finishing times of tasks 1, 2, 3,..., i,..., n, respectively. Without the loss of generality, assume the process starts at task 1 and ends at task n. Let d be the proportional reduction in cycle-time. Based on the definition above, $f_1 = t_1$ and f_n is the cycle-time of the process.

For each task i and j define binary decision variables x_{ij}'s to be 1 if i is consolidated into task j; tasks i and j can only be consolidated if they are neighboring tasks. If i is consolidated into j, then i cannot be consolidated into another task, nor can j be consolidated into i.

One direct effect of consolidation is the loss of specialization. Loss of specialization results in larger process time. It is captured in the model by changing the task-time from t_i to $(t_i + \eta_i \cdot t_i)$, where η_i is a non-negative constant.

There are other sources of consolidation costs. For example, consolidation of two tasks may increase the possibility of fraud. It can also result in increased agency costs due to the reduction of certain checks and control tasks. Task consolidation can lead to inefficient utilization of human resources due to loss of specialization. In some of these cases, certain consolidations are not allowed. These are captured by defining consolidation costs, D_{ij} (\$) as the cost of consolidating task *i* into task *j* other than those arising from loss of specialization. This cost parameter incorporates both up-front fixed cost and the overall operational costs over a specified time horizon. The latter cost is estimated as one-time operational costs times the expected number of times the process will be initiated during the said time period.

We assume that the consolidation costs are linearly additive. Hence, if task 1 precedes task2, which in turn precedes task 3, then the cost of consolidating all three tasks 1, 2, and 3 equals to cost of consolidating 1, 2 plus the cost of consolidating 2, 3. Given the input cost parameters D_{ij} for all neighboring tasks *i* and *j*, the cost of consolidation on the whole process can be expressed as $\sum_{i,j} x_{ij} \times \Delta_{ij}$.

Let δ be the cost of (or disutility) cycle time in dollar per unit time. Note that f_n is the finish time for the last task and Δ_{ij} is the cost of consolidating neighboring tasks *i* and *j*. The organization's problem of implementing the most profitable set of task consolidations is expressed by:

$$\min_{x_{ij}, f_n} \quad \delta \cdot f_n + \sum_{i,j} x_{ij} \cdot \Delta_{ij}$$

Subject to

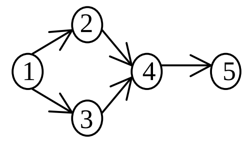
f_i is feasible, $\forall i$

x_{ij} is feasible, $\forall i, j$

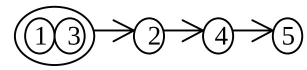
The first term in the objective function, δf_n , is the cost to the organization of having a cycle time f_n . It represents the economic losses from customer delays, slower response times. The second term in the objective function is the total consolidation cost.

While the details of the formulation are presented in the Appendix B, the salient tradeoffs incorporated in the model are presented below.

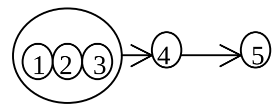
Consider the process network represented in Figure 3 below:



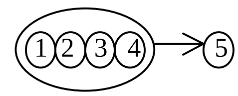
a: The original process network



b: Network after 1 and 3 are consolidated



c: Task 1, 2 and 3 are consolidated



d: Tasks 1, 2, 3 and 4 are consolidated

Figure 3: Impact of task consolidation on precedence relationships

If task 1 and 3 are consolidated, then 3 shall precede 2, resulting in the network represented in Figure 3b. Similarly, if tasks 1, 2 and 3 are consolidated, then since 2 and 3 cannot be processed at the same, one must precede the other. One possible sequence is to process 2 first. This is represented in Figure 3c.

Lastly consider a case where all but the last task are consolidated. Task 1 is consolidated into 3, 3 is itself consolidated into 4 and 2 is also consolidated into 4. The pattern of consolidation is represented in Figure 3d.

3 Impact of organizational characteristics

In this section we explore the characteristics of optimal consolidations of tasks. We determine the conditions that favor consolidation. The impact of delay costs, handoff, and loss on specialization on desirability of consolidation are examined analytically, numerically and illustrated by simple examples.

3.1 Conditions favorable for consolidation

Organizations cannot pick the optimal set of consolidations by examining each consolidation individually. Consider the example in Figure 4.

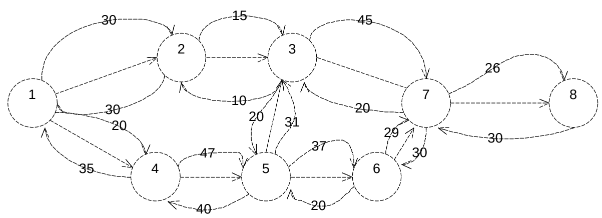


Figure 4: Process with asymmetric consolidation costs
Nodes represent tasks.
Straight arcs represent information flow.
Curved arcs represent consolidation costs.

Assume that all task times are 1. The delay between any two tasks is 2. The value of per unit of cycle-time reduction is 3 and the cost of consolidation is represented on the curved arrows. The optimal solution is $x_{21} = 1$ and $x_{34} = 1$. We see

$$\Delta_{23} = 4.9 < 2 \cdot 3 = 6 = g_{23} \cdot d,$$

but $x_{23} = 0$, which means that although consolidating task 2 into task 3 would bring positive benefits, this consolidation is not part of the optimal consolidation pattern. We see also that $g_4 * d - D_{34}$ = 2*3-5=1 and $g_3 * d - D_{23}$=2*3-4.9 = 1.1. 1<1.1, which says $g_4 * d - D_{34} < g_3 * d - D_{23}$, consolidating more task 2 into task 3 would bring more benefits than consolidating 3 and 4. But in the optimal solution, consolidating 3 and 4 is chosen over consolidating 2 and 3, i.e. $x_{34} = 1$ and $x_{23} = 0$.

The conditions favorable for consolidation illustrated by the example above are formalized in the proposition below.

Proposition 1. The optimal set of consolidations observes the following:
1). It is always the case that if task i is consolidated into task j, then $D_{ij} \leq g * d$ In other words, $D_{ij} \leq g * d$ is a necessary condition for x_{ij} to be 1;
2). However, $D_{ij} \leq g * d$ is not a sufficient condition for x_{ij} to be 1;
3). x_{ij}=1 does not necessarily imply $g * d - D_{ij} \geq g_s * d - D_{ks}$, $\forall k, s, x_{ks}$=0.

All proofs are contained in the detailed version of the work in [10].

The proposition makes it clear that it is very important for organizations to observe the scope of consolidation efforts and to plan in advance accordingly. A common mistake in BPR is to invoke changes throughout the whole organization [11]. As a result, both human and capital resources are usually spread too thin to tackle major problems that arise from dramatic change. Consider the example in Figure 4 again, the total cost corresponding to the optimal solution is 9.5. If the budget for consolidation is only 5, then only one consolidation should be implemented, namely, consolidating task 2 to task 1.

3.2 Value of per unit of cycle-time reduction

An organization's perception of the value of per unit of cycle-time reduction is an important factor as well. Delay in some processes may not be costly, although in other scenarios it can be detrimental to the success of the organization.

Proposition 2. *Value of per unit of cycle-time reduction*
If the ability and willingness to manage change is not binding, then as the value of per unit of cycle-time reduction (δ) increases, the optimal total spending on consolidations increases. This results in a more dramatic reduction in cycle-time, but the value of the objective function will strictly worsen.

The managerial implication of this proposition is that consolidation efforts should focus on processes that are more time-critical. If the changing environment renders it more critical than before to shorten the cycle-time, then larger scale consolidations should be planned for, unless the organization no longer has resources for change.

The impact of value of cycle time, δ, was also explored numerically for the general process network shown in Figure 4.

When the value of cycle time reduction (δ) increases, the firm places a greater premium on the total time of the process. The model responds by increasing the number of consolidations to reduce the cycle time. This is illustrated in figures 5 and 6 below.

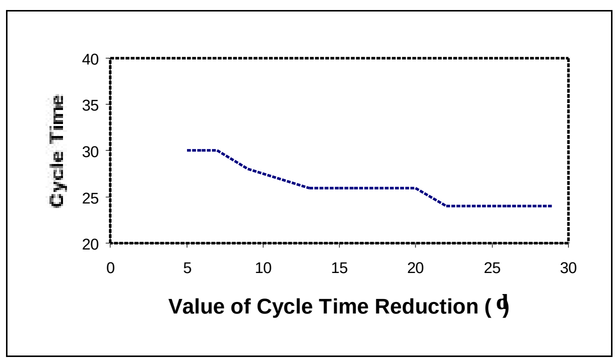


Figure 5: Tradeoff for cycle time reduction

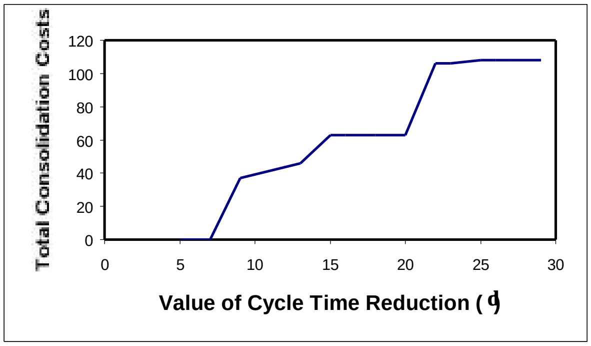


Figure 6: Tradeoff against consolidation costs

3.3 Loss of specialization

Consolidating two tasks may result in loss of specialization. As we mentioned before, loss of specialization is the increase in task time due to the fact that one person is performing multiple tasks. More specifically, t_i is increased to $t_i + \eta_i \cdot t_i$, where η_i is a certain constant and is defined as *the degree of loss of specialization*. The optimal spending on consolidation does not always decrease as a result of loss of specialization.

Consider the example depicted in Figure 7. Assume that all task times are 1. the delay between any two tasks is 2. The value of unit cycle-time reduction is 3. The costs of consolidation are represented by the numbers on the curved arcs.

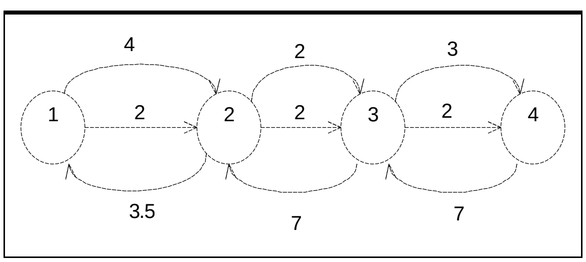


Figure 7: Example with increase in consolidation with increase in loss of specialization

Nodes represent tasks.

Straight arcs represent information flow and handoff delay.

Curved arcs represent consolidation costs.

The current optimal solution is to consolidate all tasks into one, i.e., $x_{12} = 1$, $x_{23} = 1$, and $x_{34} = 1$. The total spending on consolidation is 4+2+3=9 and the value of the objective function for a total cycle time of 4 and consolidation cost of 9 is 4*3+9=21.

Now consider due to loss of specialization, the total cycle-time of 2 and 3 after consolidation becomes 4 instead of 2, then it is not beneficial to consolidate 2 into 3 any more, the new optimal solution is $x_{21} = 1$ and $x_{34} = 1$. The total spending is 3.5+3=6.5<9. In this example, the total spending decreases when the degree of specialization increases from 0 to 100%.

To illustrate the opposite relationship where an increase in loss of specialization leads to and a decrease in spending on consolidation, consider the process depicted in Figure 8 below. This process has the same task time, delay and unit cycle-time reduction, but has different consolidation costs.

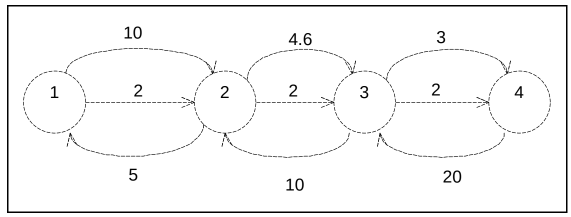


Figure 8: Example with decrease in consolidation with increase in loss of specialization

The optimal solution with no loss of specialization is to only consolidate tasks 2, 3 and 4, i.e., $x_{23} = 1$ and $x_{34} = 1$. The total spending on consolidation is 4.6+3=7.6 and the value of the objective function is the cycle time times 3 plus the consolidation cost, 6*3+7.6=25.6.

Assume that due to loss of specialization, if tasks 2 and 3 are consolidated, the combined task time would be 4 instead of 2, then it is not beneficial to consolidate 2 and 3 any more. The new optimal would be $x_{21} = 1$ and $x_{34} = 1$. The total spending is now 5+3=8>7.6. The value of the objective function is 6*3+8=26. In this example, the total spending increases when the degree of loss of specialization increases from 0 to 100%.

These results are formalized in Proposition 3.

Proposition 3. *Loss of specialization*

1. An increased degree of loss of specialization will worsen the value of the objective function.
2. As the degree of loss of specialization increases, the optimal spending on consolidation may decrease or increase. If the resulting optimal spending strictly decreases as a result of the increased degree of loss of specialization, then the total cycle-time will be strictly higher than previously. If the resulting optimal spending increases, then the new cycle-time

may be better than, worse than, or equal to the previous cycle-time.

3. Although the total spending on consolidation fluctuates as the degree of loss of specialization increases, it tends to decrease as loss of specialization gets bigger and bigger.

Proposition 3 was explored numerically using the process described in Figure 4. We set the value of unit cycle time reduction to 20 (δ=20), delay between tasks all equal to 5 (γ_{ij}=5, $\forall ij$) and set the degree of loss of specialization (η) is the same for all tasks.

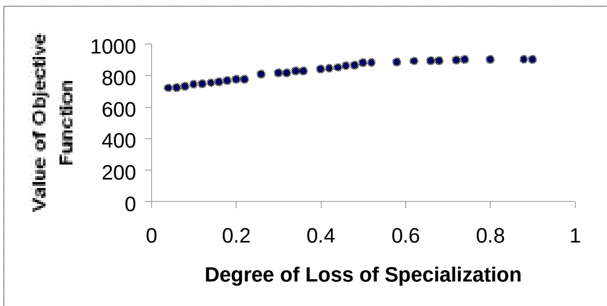


Figure 9: Impact of Degree of Loss of Specialization on organizational costs

We observe that the value of objective function monotonically deteriorates, but the total spending on the consolidation costs may increase or decrease when the degree of loss of specialization increases. Figures 9 and 10 show the effects of η on total consolidation costs and, the objective function, respectively, when η increases from 0.02 to 0.09.

Loss of specialization is a disincentive for consolidation efforts. Organizations should be aware of tasks with specific information, knowledge, or skills. Consolidating these tasks may not bring any savings but may incur high costs in implementation. Organizations should avoid consolidating these tasks and instead move efforts towards other parts of the process that would experience less loss of specialization when tasks are consolidated.

Although this proposition seems again to be a direct result of loss of specialization, in practice, organizations very often form restructuring plan without studying the impact of loss of specialization. This proposition serves as strong reminder of the impact of loss of specialization.

Information technologies, such as Database Systems and Decision Support Systems facilitate task processing usually by providing more information at lower costs. These systems reduce information specificity and decreases loss of specialization. As a result, presence of these systems will facilitate consolidation in the process, and hence result in a more centralized process structure.

3.4 Delay and hand-off times between tasks

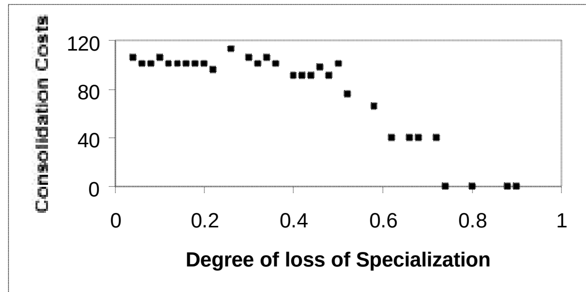


Figure 10: Impact of loss of specialization on consolidation

Reducing delay and hand-off times between tasks is the main motivation for consolidation since handoff from the upstream task to the downstream task is identified as one of the main factors of inefficiency in BPR literature [12]. When delay between tasks increase, the optimal spending on consolidation does not always increase. Consider the example represented in Figure 11. Assume all task times are 1. The delay between 1, 2 and 3, 4 is 2. The delay between 2 and 3 is 1. The value of unit cycle-time reduction is 3. The consolidation costs are represented on the curved arrows.

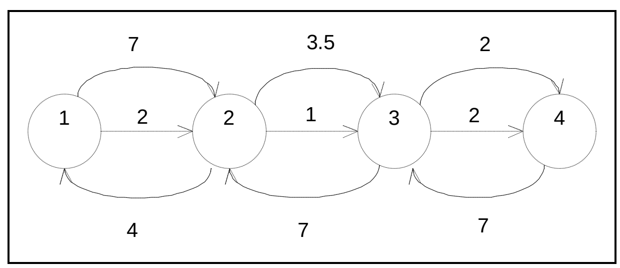


Figure 11: Process to illustrate impact of delay

Nodes represent tasks.

Straight arcs represent information flow and handoff delay.

Curved arcs represent consolidation costs.

The optimal solution is to consolidate task 2 into1 and task 3 into 4, i.e., $x_{21} = 1$ and $x_{34} = 1$. The total spending on consolidation is 4+2=6. The cycle-time is 5. The value of the objective function is 5*3+6=21.

If the delay between task 2 and 3 increases to 5, then the optimal solution is $x_{23} = 1$ and $x_{34} = 1$. The total spending on consolidation is 3.5+2=5.5<6. The cycle-time is 6. The value of the objective function is 6*3+5.5=23.5. In this example, the total spending decreases when delay between two tasks increases. The impact of delay is formalized in Proposition 4.

Proposition 4. *Delay (δ_{ij})*

When delay between two tasks increases, it may or may not have an impact on the optimal consolidation pattern. If there is an impact on the optimal pattern of consolidation, then the value of the objective function will worsen.

1) As the delay between two tasks increases, the optimal spending may increase or decrease. If the resulting optimal spending decreases as a result of the increased delay, then the total cycle-time will be worse than previously. If the resulting optimal spending increases, then the new cycle-time may be better than, worse than, or equal to the previous cycle-time.
2) Although the total spending on consolidation fluctuates, the spending as a trend tends to increase as delay gets bigger and bigger.
3) When delay between any two tasks is the same, then increase in delay between all tasks will result in more consolidations. The optimal spending on consolidation will increase. However, the value of the objective function will worsen. The total cycle-time may be worse, equal to, or better than previously.

This proposition is explored numerically for the general process net described in Figure 12. The value of unit reduction in cycle time, δ, was taken to be 10. The handoff delay was taken to be the same across all potential consolidations.

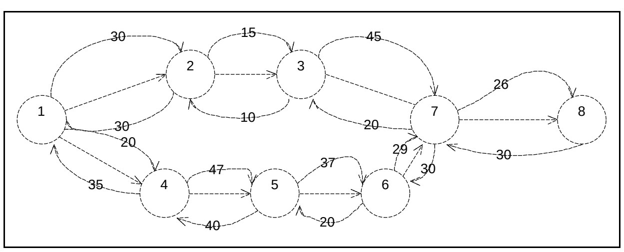


Figure 12: Another example of a process with consolidation costs

The results are shown in the graph below. In Figure 13 we see that although the general trend in the objective function cost is upwards, there are small regions over which it remains flat.

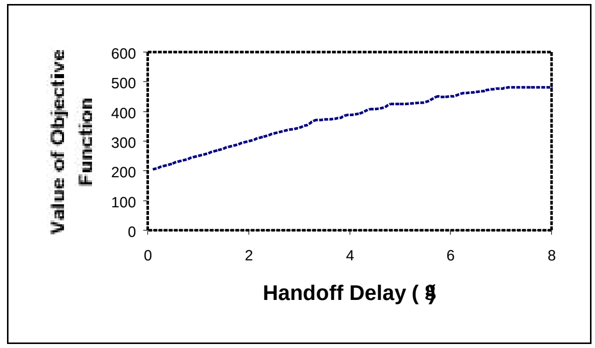


Figure 13: Impact of processing delay

The impact on cycle time and total consolidation costs is shown in Figures 14 and 15 respectively. We see that the relationship quite variable because of changes in the optimal consolidation pattern. This change is quite discontinuous and this reflects the complexity of the problem.

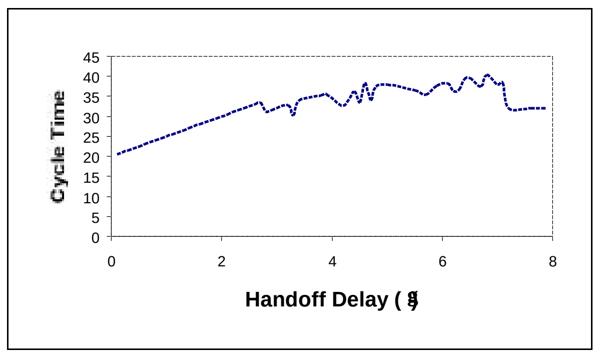


Figure 14: Processing delay and cycle time

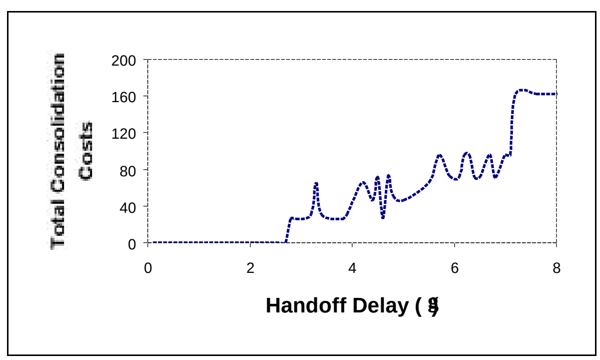


Figure 15: Processing delay and consolidations

Tasks with higher delay and hand-off times are usually the first targets for consolidation. Although process-wide increases in delays will usually demand a higher spending on consolidations to achieve the desired results, in certain scenarios, the total spending on consolidation may actually decrease as a result of increases in delays. This result appears to be counter-intuitive. The proof of this proposition provides an example of when it is the case. Organizations shall not undertake a restructuring plan at larger scale just because the delay between certain tasks has worsened. A careful study and evaluation of all options should be conducted first.

Certain types of IT, such as workflow technology and groupware technology, are designed to dramatically reduce delays and hand-off between all tasks. Adoption of these technologies makes consolidation less attractive. Presence of these systems will facilitate specialization and discourage consolidation of a process.

Value of per unit cycle-time reduction depends on the competitive position of an organization. In the short run, IT does not directly impact this parameter.

Tasks with higher delay and hand-off times are usually the first targets for consolidation. Although process-wide increases in delays will usually demand a higher spending on consolidations to achieve the desired results, in certain scenarios, the total spending on consolidation may actually decrease as a result of increases in delays. Organizations shall not undertake a restructuring plan at larger scale just because the delay between certain tasks has worsened. A careful study and evaluation of all options should be conducted first.

3.5 Consolidation costs

Consolidation costs are costs incurred to implement consolidation of two neighboring tasks. Depending on the nature of the consolidation, this cost may come from either decreased value of decision-making or increased cost of conducting the tasks involved. The value of a task may decrease due to, for example, misalignment of decision rights and incentives or declining of task quality due to lack of specific knowledge or skills. The cost of a task may increase due to, for example, either fixed training costs or higher variable labor costs.

Proposition 5. *Cost of consolidation (D_{ij})*

1) As the cost of consolidation increases, the value of the objective function will worsen.
2) The optimal total spending on consolidation may increase or decrease. If the resulting optimal spending decreases as a result of the increased cost of consolidation, then the total cycle-time will be higher than previously. If the resulting optimal spending increases, then the new cycle-time may be better than, worse than, or equal to the previous cycle-time
3) Although the optimal total spending on consolidation fluctuates with decreases in consolidation costs, the spending as a trend tends to decrease as the consolidation costs gets bigger and bigger.

Tasks with highly specific information or designed for management control are usually not good candidates for consolidation unless other means are available to mitigate costs from lack of control. When costs of consolidations increase, organizations shall not automatically expect to spend more on consolidation. Instead, organization shall reevaluate its option. The optimal consolidation pattern at this point may be one with much less total spending.

IT that provides support for managerial control reduces the costs from misalignment of incentives. Hence it reduces cost of consolidation. Consequently, it will facilitate consolidation.

Similar to the effects of loss of specialization, increase in consolidation costs mean result in either decreased or increased total spending on consolidation. Consolidation costs are costs incurred to implement consolidation of two neighboring tasks. Depending on the nature of the consolidation, this cost may come from either decreased value of decision-making or increased cost of conducting the tasks involved. The value of a task may decrease due to, for example, misalignment of decision rights and incentives or declining of task quality due to lack of specific knowledge or skills. The cost of a task may increase due to, for example, either fixed training costs or higher variable labor costs.

Consider the Figure 16 below. Assume all task times are 1. Delay between any two tasks is 2. The value of unit time reduction is 3. The consolidation costs are represented on the curved arcs.

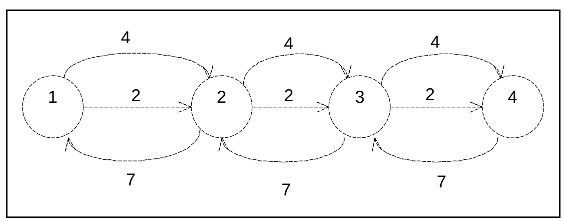


Figure 16: Consolidation Cost example

The optimal solution is $x_{12} = 1$, $x_{23} = 1$ and $x_{34} = 1$. The total spending is 4+4+4=12. If the consolidation cost Δ_{34} increases from 4 to 5, the optimal solution remains the same. However, the total spending increases from 12 to 13. If the consolidation cost Δ_{34} increases again from 5 to 6.5, then the optimal solution becomes $x_{12} = 1$ and $x_{23} = 1$. The total spending reduces to 8.

Tasks with highly specific information or designed for management control are usually not good candidates for consolidation unless other means are available to mitigate costs from lack of control.

4 Summary of Results and Discussions

The organization's bounded ability and willingness to manage change will result in less spending on consolidations than otherwise. As a result, reduction in the total cycle time will be less dramatic and the value of the objective function will be greater.

If the value of unit cycle time reduction increases, then the optimal spending on consolidation will increase. There will be more dramatic change in total cycle time, although the value of the objective function increases regardless. However, if the bounded ability constraint is already binding then increase in the value of unit cycle time reduction will have no impact on the consolidation pattern.

Loss of specialization serves as a disincentive for consolidation. During any small increase in the degree of loss of specialization, the total spending and the total cycle time may increase or decrease, but as the magnitude of change increases, the total spending tends to decrease and the total cycle time tends to increase.

Delay and hand-off between tasks serve as an incentive for consolidation. During any small increase in delay between two tasks, the total spending and the total cycle time may decrease or increase. However, the value of the objective function may only increase or remains the same. As the magnitude of change in delay increases, the total spending tends to increase. However, the total cycle time will also increase.

Costs of consolidation serve also as a disincentive for consolidation. During any small increase in consolidation costs, the total spending and the total cycle time may decrease or increase. However, the value of the objective function may only increase or remains the same. As the magnitude of change in consolidation costs increases, the total spending tends to decrease; the total cycle time will increase and the value of the objective function will increase.

Since information systems and information technology (IT) can dramatically reduce delay and handoff between all tasks, they make consolidation less attractive. On the other hand, IT reduces Δ_{ij} by increasing the value of decision and reducing the cost of decision-making. On that front, consolidation will become more attractive. The impact of technology on consolidation is then determined by the overall effect of IT on the whole process. Since different technologies have different impacts on reducing delay or reducing Δ_{ij}, they will have different effects on the pattern of consolidation.

Information technology which facilitates task processing (reduce information specificity and loss of specialization) by providing more information at lower costs will facilitate consolidation. IT that reduces delays between tasks (workflow technology) will facilitate specialization, as well as checks and control.

IT impact literature indicates that IT sometimes facilitates centralized decision making and sometimes facilitates decentralized decision making. One common conclusion is that IT helps align incentives with decision rights by reducing information specificity and communication costs. Information technologies that support task processing by reducing information specificity or skill specificity (such as decision support system) will then facilitate consolidation to eliminate delay between tasks. Information technologies that reduce hand-off times or delay between tasks will then encourage checks and control because only then are incentives best aligned with decision rights. This type of technology will also facilitate specialization, because only then are the skill sets best aligned with decision rights.

5 Conclusions

We provide a new powerful approach to restructuring effective business processes. Our approach explores the fact that in a large number of business applications the overall task time is determined by handoff delays and errors incurred when information is communicated between tasks. The methodology presented here accommodates precedence requirements and pays special attention to tasks, which require specific information, knowledge, or skills. It considers the key tradeoffs between cycle time reduction and loss of specialization. Our results indicate when organizations could achieve good results due the elimination of handoffs.

Using consolidation as a unified methodology to come up with redesign initiatives is based on the common observation that delay and hand-off are one of the main reasons why so many processes are inefficient. The consolidation method presented here is applicable to multiple task business processes. Using a mathematical model we can optimally redesign complex process networks and incorporate many of the salient organizational change issues that are fundamental to the success of any reengineering effort. Several applications of the proposed methodology several important insights regarding the relationship between the cost of consolidation, cycle time delays, structure of tasks and information flow associated with handoffs.

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Appendix A

<u>Summary of Notations</u>

Given variables and parameters:

i , j , k : indices for tasks.

n : number of tasks in the process;

a_{ij} : indicator function, 1 if there is a directed arc from *i* to *j*. a_{ij} is not transitive, i.e., the input to the directed graph is minimal and does not contain any redundant inputs. Thus if $a_{ij} = 1$, and $a_{jk} = 1$, then $a_{ik} = 0$;

b_{ij}: 1 if there is a directed path from *i* to *j*, 0 otherwise;

t_i : processing time duration of task *i*;

g_j : processing delay between *i* and *j*;

d: dollar value of unit cycle time reduced from the current cycle time;

T_0 : current cycle time;

Δ_{ij} : cost of consolidating *i* into *j*;

N : set $1..n$;

M : a big number, $M > T_0$;

Decision Variables:

f_i : finishing time of *i*. Assume that the process starts at 1 and ends at *n*;

x_{ij} : indicator function, 1 if *i* is consolidated into *j* so that *j* is now performing tasks previously done by either *i* or *j*;

Dependent variable:

y_{ij} : indicator function, 1 if *i* must finish before *j* can start, 0 otherwise.

w_{ij}: indicator function, 1 if *i* and *j* are done by the same worker; 0 otherwise;

u_{ij}: indicator function, 1 if there exist $i_1, i_2, \ldots, i_k$, such that $x_{i,i1}=1, x_{i2,i3}=1, \ldots, x_{ik,j}=1$.

Appendix B

The complete formulation, **PACP**:

$$\min_{x_{ij}, f_n} \quad d f_n + \sum_{i,j \in N} \Delta_{ij} x_{ij}$$

Subject to

$$f_j - t_j \geq f_i + g_j (1 - w_{ij}),\ \forall i, j, a_{ij} = 1 \quad (1)$$

$$f_j - t_j \geq f_i + g_j (1 - w_{ij}) - M(1 - y_{ij}),$$
$$\forall i \neq j, b_{ij} = 0, b_{ji} = 0. \quad (2)$$

$$y_{ik} \geq w_{jk} - w_{ij},\ \forall i > k, j, a_{ij} = 1, b_{ik} = 0, b_{ki} = 0 \quad (3)$$

$$y_{ik} \geq w_{jk},\ \forall i < k, j, a_{ij} = 1, b_{ik} = 0, b_{ki} = 0 \quad (4)$$

$$y_{kj} \geq w_{ki} - w_{ij},\ \forall k > j, i, a_{ij} = 1, b_{jk} = 0, b_{kj} = 0 \quad (5)$$

$$y_{kj} \geq w_{ki},\ \forall k < j, i, a_{ij} = 1, b_{jk} = 0, b_{kj} = 0 \quad (6)$$

$$w_{ij} \leq u_{ji} + u_{ij} + \sum_k u_{ik} \cdot u_{jk},\ \forall i < j \quad (7)$$

$$w_{ij} \geq x_{ij} + x_{ji},\ \forall i < j \quad (8)$$

$$w_{ij} \geq w_{ik} + w_{kj} - 1,\ \forall i < j, k \neq j \quad (9)$$

$$w_{ij} = w_{ji},\ \forall i > j \quad (10)$$

$$u_{ij} \leq x_{ij} + \sum_{k \neq j \neq i} x_{ik} \cdot u_{kj},\ \forall i \neq j \quad (11)$$

$$u_{ij} \geq x_{ij},\ \forall i, j, a_{ij} + a_{ji} = 1 \quad (12)$$

$$u_{ij} \geq u_{ik} + u_{kj} - 1,\ \forall i \neq k \neq j \quad (13)$$

$$u_{ii} = 1,\ \forall i \quad (14)$$

$$u_{ij} + u_{ji} \leq 1,\ \forall i \neq j \quad (15)$$

$$x_{ij} + x_{ji} \leq a_{ij} + a_{ji},\ \forall i, j, \quad (16)$$

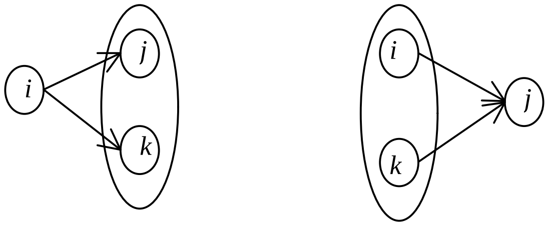
$$\sum_j x_{ij} \leq 1,\ \forall i \quad (17)$$

$$f_1 = \tau_1 \quad (18)$$

$$x_{ij}, u_{ij}, w_{ij}, y_{ij} \in (0,1),\ \forall i, j \quad (19)$$

Constraint (1) preserves the input precedence relationships specified by a_{ij}'s. Whether or not there will be any delay between *i* and *j* is captured by w_{ij}. Constraint (2) states that if a new precedence relationship is created between tasks *i* and *j*, *j* cannot start until *i* has finished and the expected time delay has elapsed. Using the big constant M allows us to replace two constraints with one without loss of generality. It states that the finish time for task *j* must be larger than that for *i* by the handoff time if they are not consolidated and done by different workers.

Constraints (3) and (4) represent one type of structural change in which new precedence relationships



a: If i precedes j and k is consolidated with j, then if $i < k$, or i and j are not consolidated ($w_{ij} = 0$), then i must precede k.

b: If i precedes j and k is consolidated with j, then if $k < j$, or i and j are not consolidated ($w_{ij} = 0$), then k must precede j

Figure 17: Change in process

are created. We divide the constraints into two sets $i>k$, and $i<k$. To understand the rationale, consider Figure 17. If tasks i, j, and k are all consolidated into one task, either i must precede k or k must precede i. Both scenarios have the same effect on the total cycle-time, hence they are equivalent with respect to *PACP*. In order to reduce problem size, I assume that the one with smaller index number precedes the other. Constraint (3) states that if i precedes j (a_{ij}=1) and $i>k$, then i precedes k only if i is consolidated with j (w_{ij}=1). Constraint (4) states that if i precedes j (a_{ij}=1), and $i<k$, then i must precede k, whether i is consolidated with j or not. Constraints (5) and (6) represent the second type of structural change in which new precedence relationships are created. Constraint (5) states that if i precedes j (a_{ij}=1) and $k>j$, then k precedes j only if i is consolidated with j (w_{ij}=1). Constraint (6) states that if i precedes j (a_{ij}=1), and $k<j$, then k must precede j, whether i is consolidated with j or not.

Constraints (7) through (10) define variables w_{ij}'s through u_{ij}'s.

To obtain w_{ij}'s, let's consider a new graph with the same vertices, 1 to n, but arcs are represented by x_{ij}'s, that is, there is a directed arc from i to j only if x_{ij}=1. Thus each node can have only one outgoing arc and many incoming arcs. Moreover, the graph is acyclic. w_{ij} is 1 if and only if there exists a node k (1 to n) such that there is a directed path from i to k and another from j to k. Let the binary decision variable u_{ij} be 1 if there is a directed path from i to j, 0 otherwise. Mathematically, u_{ij} is 1 if there exist i_1, i_2, …, i_k, such that $x_{i,,i1}$=1, $x_{i2,i3}$=1, …, $x_{ik,j}$=1, that is i is consolidated into j indirectly through i_1, i_2, …, i_k. The relationship among x_{ij}, w_{ij} and u_{ij} is illustrated in Figure 18 below.

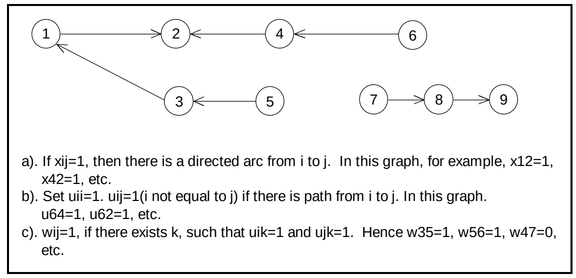


Figure 18: Relationship between variables

Constraint (7) states that w_{ij}=0 if none of the following three conditions is satisfied:
i is directly or indirectly consolidated into j (u_{ij}=1);
j is directly or indirectly consolidated into i (u_{ji}=1);
there exists a k, such that i is directly or indirectly consolidated into k (u_{ik}=1), and j is also directly or indirectly consolidated into k (u_{jk}=1).

Constraint (8) states that if two neighboring tasks i and j are consolidated, then w_{ij}=1. Constraint (9) captures the transitivity of w_{ij}. Constraint (10) captures the symmetry of w_{ij}.

Constraints (11) through (15) define u_{ij}'s. Constraint (11) states that u_{ij}=0 if none of the following two conditions is met:
i and j are directly consolidated (x_{ij}+x_{ji}=1)
there exists a k such that i is directly consolidated into k (x_{ik}=1) and k is indirectly consolidated into j (u_{kj}=1).

Constraint (12) states that u_{ij} =1 if i is directly consolidated into j (x_{ij}=1). Constraint (13) captures transitivity of u_{ij}. Constraint (15) states that if u_{ij} =1 then u_{ji}=0.