



## Quantifying the Effectiveness of Interventions in Workflows

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## Quantifying the Effectiveness of Interventions in Workflows

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**Abstract:** Workflows are common in today's business world, and are an integral part of current ECM, PLM and ERP systems. When a task assignee does not complete a task on time, workflow systems are commonly configured to send out reminders. Reminders are a form of intervention in the workflow. It's tacitly assumed that workflow intervention is effective, yet, to date, there has been no quantitative characterization of the benefits of workflow intervention.

This study first develops a mathematical model for workflow intervention. The controlling parameters are identified: the choice of probability distribution, the skewness of the probability distribution, the intervention interval and the effectiveness of individual interventions. To the extent that closed-form solutions are available (e.g. for uniform or triangular probability density functions), they are presented. More generally, results are presented by representing the wait time using the weibull probability density function. Cases where closed-form solutions are intractable are simulated using the Petri net method.

Results indicate that, while interventions always reduce the mean cycle time for a workflow, there are certain circumstances where the cycle time reduction is dramatic (i.e. > 50%).

**Keywords:** Business process redesign, workflow intervention, reminders, notifications, best practices, performance measurements.

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### 1. INTRODUCTION

A business process is a collection of steps or tasks which are sequenced to achieve an ultimate objective. Work done by one individual, while of critical importance, is not normally considered a business process. The "process" aspect implies multiple resources, which may be human, machinery or information systems.

Business processes are occasionally changed in a large scale using radically different approaches: e.g. Henry Ford's use of the assembly line concept, the business process re-engineering revolution popularized by Hammer and Champy [1]. On a smaller scale, business processes are often characterized by or even called "workflows". Changes on this smaller scale are often termed "business process improvements", and many of the applicable techniques were catalogued by Reijers [2]. With the use of electronic workflows in product lifecycle management systems ("PLM"), enterprise content management systems ("ECM"), and enterprise resource planning systems ("ERP"), it's common to monitor the progress of individual task assignments and send reminders to the assignee if the task completion is late. This is an intervention tactic, is widely applicable, and can be used in conjunction with the aforementioned techniques.

Philosophically, the intervention approach is discouraged [3] since all intervention is a waste of resources. Nonetheless, intervention is justifiable when deadlines require that something be accomplished quickly, and the task otherwise wouldn't be completed in time.

This paper examines the key question related to intervention: does intervention actually reduce business process cycle times, and, if so, by how much? This study will not examine the psychological aspects nor the attitude of the recipient of the intervention/reminders, although these factors undoubtedly have an effect.

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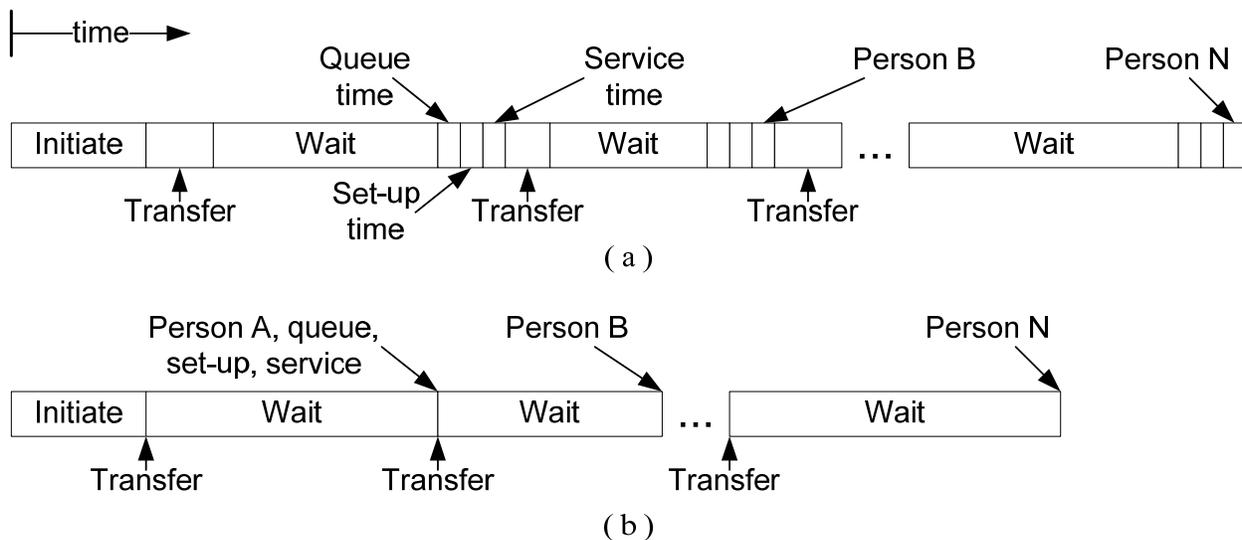
Some authors have quantified the benefits for certain business process improvement techniques [4,5]. But, quantifying business process improvements is challenging since there are precious few cases which lead to closed form solutions, therefore a different approach, such as simulation, is needed. Over the last decade, simulations based on the Petri Net technique have been proposed and qualified as being effective for the analysis of workflows [6,7]. Timed, stochastic Petri Net simulations are used in this study to quantify the effectiveness of interventions in workflows. Although optimality criteria such as cost and quality [4] may be relevant to intervention strategy, this study measures effectiveness strictly in terms of time reductions.

Figure 1(a) is a high-level timing diagram of a simple business process. It contains the following essential elements:

1. The business process must be initiated. The initial actor may be a person, or an electronic agent.
2. Once initiated, the associated artifacts (i.e. the “form” or attachments, if any) must be transferred to the next actor in the process. Traditionally this was done by putting documents into a file folder and moving the folder from the “out” basket of one person to the “in” basket of another person.
3. Once the artifacts arrive at the next person’s “in” basket, the process waits for the person to become available. There may be other, similar tasks in the person’s “in” basket, thereby creating a queuing delay.
4. Once the person is available, s/he performs the associated task, perhaps after performing some set-up if necessary (e.g. turn on a computer, activate the application).
5. Steps 2 through 4 repeat for each additional actor in the business process.

The time to perform the task may be comprised of setup time (e.g. time to turn on a computer and activate the necessary applications), queue time (i.e. the time for other, similar tasks to be performed) and service time (i.e. the time to perform the task that is the subject of the workflow).

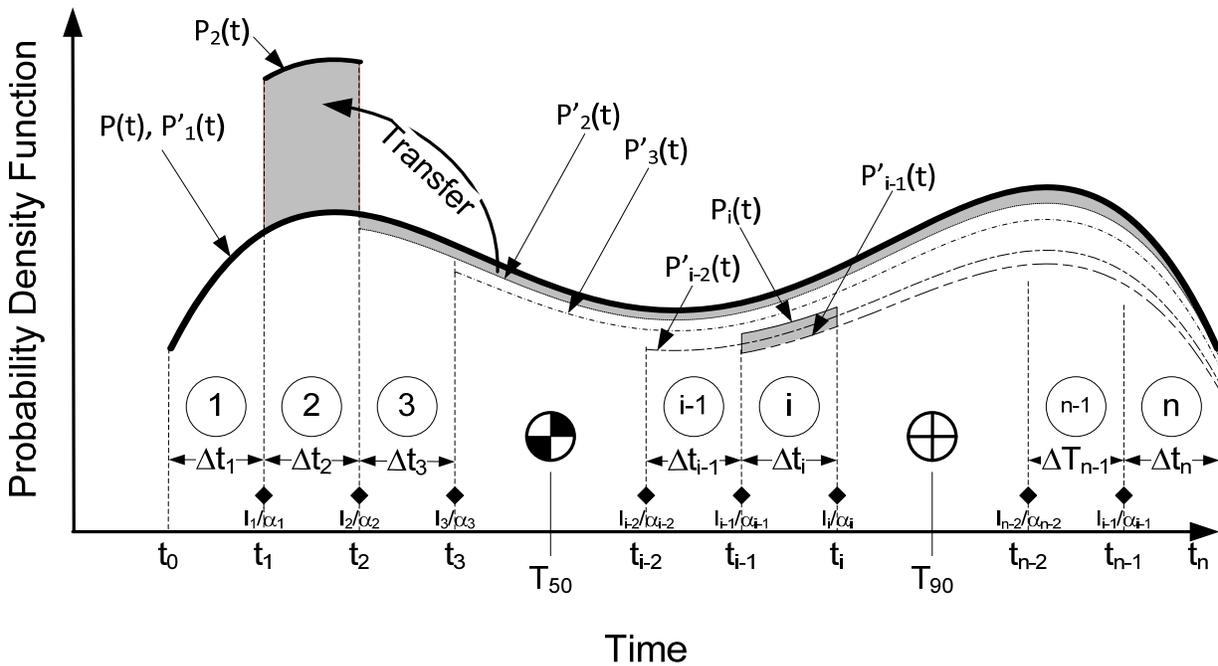
Figure 1 implies that most of the time is consumed in wait states: i.e. the business process artifacts are available to be worked on, but the process is waiting for the availability of the resource. This would certainly be true of a business process like engineering change management where the job packet is processed by a given person, typically for just a few minutes, following hours or days of inactivity. More generally, business processes which involve reviews and approvals also follow this model where the time to complete the work (service time), the queuing delays and the set-up time are all a very small fraction of the overall cycle time of the business process. Since today’s electronic workflow systems can transfer work packets from one person to the next within seconds, the transfer time is negligible. With these simplifications, this type of business process is really governed by the length of the wait times, as shown in Figure 1b.



**Figure 1. High-level business timing diagram.**

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The wait times for various tasks will generally have different values, but they can be represented by a probability distribution, as depicted in Figure 2.



**Figure 2. Wait time probability distribution.**

This probability distribution can be characterized by the following variables:

- $P(t)$  the probability density function for this probability distribution. By definition the area under the  $P(t)$  curve is identically equal to 1.
- $t_0$  the minimum wait time. No wait times can be below this value. For simplicity, assume  $t_0 = 0$ .
- $t_n$  the maximum wait time. No wait times can exceed this value.
- $T_{50}$  50% of the waits will be less than this value. That is 50% of the occurrences are less than this value.  $T_{50}$  is termed the “characteristic time” of the probability density function.
- $T_{90}$  90% of the waits will be less than this value. That is 90% of the occurrences are less than this value.
- $T_{90}/T_{50}$  A ratio proportional to the skewness of the probability distribution, and termed the “skewness ratio” in this paper.

The wait time is a measure of the business process inefficiency; that is the greater the wait time for a single transaction, the greater the total cycle time of the business process, and the less efficient the process is. Whatever the wait time distribution, individual wait times will often be viewed by practitioners as being “too long”, hence the desire for interventions in an attempt to “speed things up”.

## 2. ANALYSIS

Define:

- $n$  the number of intervals between  $t_0$  and  $t_n$
- $\Delta t_i$  the duration of interval  $i$
- $l_i$  intervention event  $i$

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- $\alpha_i$  the effectiveness of an individual intervention  $i$ .  $0 \leq \alpha_i \leq 1$ .
- $\gamma$  the net intervention efficiency
- $P'_i(t)$  the modified probability density function, including the effects of all prior interventions,  $I_1$  thru  $I_{i-1}$ . Since there is no intervention  $I_0$ ,  $P'_1(t) \equiv P(t)$ .
- $D_i$  the probability that the wait time will terminate during interval  $i$

Consider a step of a business process which has a wait time distribution as shown in Figure 2. The probability distribution is divided into  $n$  intervals. The probability that the wait time will fall in the interval between  $T_0$  and  $T_1$  is represented by  $D_1$  and represented graphically by the area under the  $P(t)$  curve in the same interval.

$$D_1 = \int_{t_0}^{t_1} P(t) dt \quad (1)$$

At time  $t_1$ , the first intervention,  $I_1$ , takes place. It's assumed that this has no affect on the wait times that would have normally concluded during the interval  $t_1$  thru  $t_2$ , but intervention  $I_1$  does have an impact on some portion, represented by  $\alpha_1$ , of the wait times that would have concluded between  $t_2$  and  $t_n$ . The graphical interpretation is that the area under the  $P(t)$  curve between  $t_2$  and  $t_n$ , multiplied by  $\alpha_1$  is added to the area under the  $P(t)$  curve between  $t_1$  and  $t_2$ . In Figure 2, this is shown as the "transfer" of shaded area directly beneath the  $P'_1(t)$  curve to the shaded area directly beneath the  $P_2(t)$  curve. For simplicity, it's assumed that this "extra" area is evenly distributed along the interval  $t_1$  to  $t_2$ . So the probability that the wait time concludes in the interval  $t_1$  to  $t_2$ , accounting for the impact of the intervention  $I_1$  is  $D_2$ :

$$\begin{aligned} D_2 &= \int_{t_1}^{t_2} P(t) dt + \alpha_1 \int_{t_2}^{t_n} P'_1(t) dt \\ &= \int_{t_1}^{t_2} P(t) dt + \alpha_1 \int_{t_2}^{t_n} P(t) dt \end{aligned} \quad (2)$$

This transfer effect means that the effective probability density function, in the interval  $t_1$  to  $t_2$ , becomes:

$$\begin{aligned} P_2(t) &= P'_1(t) + \frac{\alpha_1}{\Delta t_2} \int_{t_2}^{t_n} P'_1(t) dt \\ &= P(t) + \frac{\alpha_1}{\Delta t_2} \int_{t_2}^{t_n} P(t) dt \end{aligned} \quad (3)$$

But the probability density function for the remaining intervals is reduced. Let's term this  $P'_2(t)$ :

$$P'_2(t) = P(t)(1 - \alpha_1) \quad (4)$$

If intervention  $I_1$  were fully effective ( $\alpha_1 \equiv 1$ ), then  $P'_2(t) = 0$ , since all of the wait times would have terminated in the interval  $t_1$  to  $t_2$ . If intervention  $I_1$  were totally ineffective ( $\alpha_1 \equiv 0$ ), then  $P'_2(t) = P(t)$ , since the intervention has changed nothing about the probability of the wait times terminating.

The same logic can be applied to determine the probability  $D_3$  and the modifications to the probability density function  $P'_3(t)$ .

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$$D_3 = \int_{t_2}^{t_3} P'_2(t) dt + \alpha_2 \int_{t_3}^{t_n} P'_2(t) dt \quad (5)$$

$$= \int_{t_2}^{t_3} P(t)(1 - \alpha_1) dt + \alpha_2 \int_{t_3}^{t_n} P(t)(1 - \alpha_1) dt$$

$$P_3(t) = P(t)(1 - \alpha_1) + \frac{\alpha_2}{\Delta t_3} \int_{t_3}^{t_n} P(t)(1 - \alpha_1) dt \quad (6)$$

$$P'_3(t) = P'_2(t)(1 - \alpha_2) \quad (7)$$

$$P'_3(t) = P(t)(1 - \alpha_1)(1 - \alpha_2)$$

Further extending this to the general case:

$$D_i = \int_{t_{i-1}}^{t_i} P(t) \prod_{j=1}^{i-2} (1 - \alpha_j) dt + \alpha_{i-1} \int_{t_i}^{t_n} P(t) \prod_{j=1}^{i-2} (1 - \alpha_j) dt$$

$$= \left( \prod_{j=1}^{i-2} (1 - \alpha_j) \right) \left( \int_{t_{i-1}}^{t_i} P(t) dt + \alpha_{i-1} \int_{t_i}^{t_n} P(t) dt \right) \quad 3 \leq i \leq n \quad (8)$$

$$P_i(t) = P(t) \prod_{j=1}^{i-2} (1 - \alpha_j) + \frac{\alpha_{i-1}}{\Delta t_i} \int_{t_i}^{t_n} P(t) \prod_{j=1}^{i-2} (1 - \alpha_j) dt$$

$$= \left( \prod_{j=1}^{i-2} (1 - \alpha_j) \right) \left( P(t) + \frac{\alpha_{i-1}}{\Delta t_i} \int_{t_i}^{t_n} P(t) dt \right) \quad 3 \leq i \leq n \quad (9)$$

$$P'_i(t) = P'_{i-1}(t)(1 - \alpha_i)$$

$$P'_i(t) = P(t)(1 - \alpha_1)(1 - \alpha_2) \dots (1 - \alpha_i)$$

$$P'_i(t) = P(t) \prod_{j=1}^{i-1} (1 - \alpha_j) \quad 2 \leq i \leq n \quad (10)$$

The average time wait time, for a given probability distribution, is:

$$\bar{t}_0 = \frac{\int_{t_0}^{t_n} t \cdot P(t) dt}{\int_{t_0}^{t_n} P(t) dt}$$

$$\bar{t}_0 = \int_{t_0}^{t_n} t \cdot P(t) dt \quad \text{since} \quad \int_{t_0}^{t_n} P(t) dt \equiv 1 \quad (11)$$

Accounting for the interventions, the average wait time becomes:

$$\bar{t}_\alpha = \int_{t_0}^{t_1} t \cdot P(t) dt + \int_{t_1}^{t_2} t \cdot P_2(t) dt + \sum_{i=3}^n \int_{t_{i-1}}^{t_i} t \cdot P_i(t) dt$$

$$\bar{t}_\alpha = \int_{t_0}^{t_1} t \cdot P(t) dt + \int_{t_1}^{t_2} t \cdot \left( P(t) + \frac{\alpha_1}{\Delta t_2} \int_{t_2}^{t_n} P(t) dt \right) dt \quad (12)$$

$$+ \sum_{i=3}^n \left[ \int_{t_{i-1}}^{t_i} t \cdot \left( \prod_{j=1}^{i-2} (1 - \alpha_j) \right) \left( P(t) + \frac{\alpha_{i-1}}{\Delta t_i} \int_{t_i}^{t_n} P(t) dt \right) dt \right]$$

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The net intervention efficiency,  $\gamma$ , can be defined as:

$$\gamma = 1 - \frac{\bar{t}_\alpha}{\bar{t}_0} \quad (13)$$

Clearly  $\gamma = 0$  represents the case where the interventions have no net beneficial effect.  $\gamma = 1$  represents the limiting case where the intervention strategy is perfect.

### EXAMPLE 1

Consider a simple example, with the following parameters:

$$t_0 = 0; t_n = 2$$

The probability density function is uniform  $\therefore P(t) = \frac{1}{t_n - t_0} = \frac{1}{2}$

The characteristic time,  $T_{50} = 1.0$

Interventions occur on equal intervals,  $\Delta t_1 = \Delta t_2 = \dots = \Delta t = 0.5$

Therefore,  $t_1 = 0.5; t_2 = 1.0; t_3 = 1.5; t_4 = 2.0$

The intervention effectiveness is constant,  $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha = 0.50$

The results of the previous analysis yield the following:

$$P(t) = \frac{1}{t_n - t_0} = \frac{1}{2}$$

( 1 ) becomes 
$$D_1 = \int_0^{0.5} \frac{1}{2} dt = 0.25$$

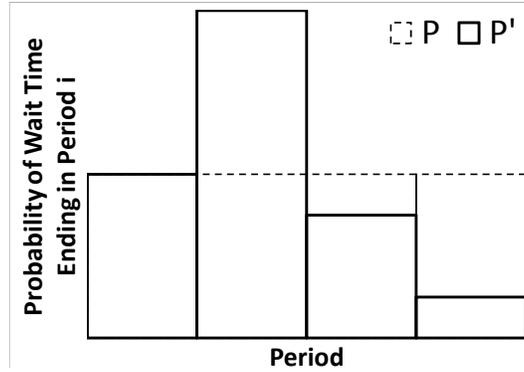
( 10 ) becomes 
$$P'_i = \frac{1}{2} \prod_{j=1}^{i-1} (1 - \alpha) = \frac{1}{2} (1 - \alpha)^{i-1} \quad 2 \leq i \leq 4$$

For  $i = \{2, 3, 4\}; P'_i = \{0.25, 0.125, 0.0625\}$

( 8 ) becomes 
$$D_i = \int_{t_{i-1}}^{t_i} \frac{1}{2} (1 - \alpha)^{i-2} dt + \alpha_{i-1} \int_{t_i}^{t_n} \frac{1}{2} (1 - \alpha)^{i-2} dt$$

$$= \frac{1}{2} (1 - \alpha)^{i-2} \cdot \Delta t [1 + \alpha(n - i)]$$

For  $i = \{1, 2, 3, 4\}; D_i = \{0.25, 0.5, 0.1875, 0.0625\}$



**Figure 3. Impact of intervention on probability of wait time ending in a specific interval, as per example 1.**

( 11 )  
becomes 
$$\bar{t}_0 = \int_{t_0}^{t_n} \frac{1}{2} t dt = 1.0$$

( 12 )  
becomes 
$$\bar{t}_\alpha = \int_{t_0}^{t_1} \frac{1}{2} t dt + \sum_{i=2}^n \int_{t_{i-1}}^{t_i} \frac{1}{2} t \prod_{j=1}^{i-1} (1 - \alpha) dt = 0.78125$$

So, 
$$\gamma = \frac{\bar{t}_\alpha}{\bar{t}_0} = 1 - \frac{0.78125}{1.0} = 0.21875 \tag{ 14 }$$

Interestingly, from ( 14 ), intervention efficiency of  $\alpha = 50\%$ , under these conditions, reduces the average wait time by 21.875%.

### 3. SENSITIVITY TO CONTROLLING PARAMETERS

The derivation shown in the previous section is fundamentally correct. The performance improvement, shown in Figure 3 and equation ( 14 ), depends on 4 assumptions:

1. The choice of probability density function
2. The skewness of the probability density function
3. The timing of the interventions,  $\Delta t_i$ ,
4. The intervention effectiveness,  $\alpha_i$

#### 3.1 CHOICE OF PROBABILITY DENSITY FUNCTION

The probability density function, used in example 1, was uniform. In most cases, the true probability density function for wait times is unknown. A thought experiment can provide some guidance, however. It's reasonable that the approval wait time distribution would be low at the start, rise to some maximum (i.e. the time it takes for, say, the "average" person to approve a work item), and then tail off with some laggards at the end. The uniform distribution does not have this characteristic. However, the triangular probability density function, does have this characteristic and is the simplest piecewise linear probability density function. A continuous distribution that can exhibit a maximum point is the weibull probability density function. The normal or Gaussian distribution does not qualify since one of the tails of the distribution goes to  $-\infty$ , and that would violate the constraint that no work item can be completed prior to its existence.

In order to make a meaningful comparison between these distributions, the parameters were carefully chosen so that each distribution has values of  $T_{50} = 1.0$  and  $T_{90} = 1.8$ . In each case when the weibull probability density function is used, in this paper, the results have been obtained from a simulation using the Petri Net technique. A separate study was conducted ensure that simulation results have converged

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to one part in  $10^4$ . Furthermore, the Uniform and Triangular distribution results of Table 1, which were calculated using the derivation in Example 1, have closed-form solutions and were used to validate the results of corresponding Petri Net simulations. This provided confidence that the values of  $\gamma$  from the Petri Net simulations had indeed converged to  $\pm 0.01\%$ . Since these are simulation results, a large number of iterations are needed in order for the net results to converge to a stable value. In this case  $10^7$  iterations are needed in order for the results to converge to  $\pm 0.0001$ .

Probability Density Function	Equation	$\gamma = 1 - \frac{\bar{t}_\alpha}{\bar{t}_0}$	Graph
Uniform	$P(t) = 0.5 \quad 0 \leq t \leq 2$	21.9%	
Triangular	$P(t) = \begin{cases} \frac{2t}{bc} & 0 \leq t \leq c \\ \frac{2(b-t)}{b(b-c)} & c \leq t \leq b \end{cases}$ $\begin{aligned} b &\cong 2.447 \\ c &\cong 1.197 \end{aligned}$	20.3%	
Weibull	$P(t) = \left(\frac{\kappa}{\lambda}\right) \left(\frac{t}{\lambda}\right)^{(\kappa-1)} e^{-\left(\frac{t}{\lambda}\right)^\kappa}$ $\kappa \cong 2.042, \lambda \cong 1.197$	21.0%	

**Table 1. Sensitivity of intervention effectiveness to choice of probability density function.**

### 3.2 SKEWNESS OF THE PROBABILITY DENSITY FUNCTION

The results presented in Table 1 show little dependence on the choice of probability density function. However the parameters for each probability density function are carefully chosen to make the results comparable; specifically  $T_{90}/T_{50} = 1.8$ . While the  $T_{90}/T_{50}$  ratio, which represents the skewness of the distribution, can theoretically fall anywhere in the range  $1 < T_{90}/T_{50} < \infty$ , in practice a more common range would be  $1 < T_{90}/T_{50} < 10$ . The shape of the weibull probability density function changes with the values of  $T_{90}/T_{50}$ , as shown in Figure 4.

In the range  $1 < T_{90}/T_{50} < 10$ , as shown in Figure 5, the net intervention efficiency varies greatly with the skewness ratio. The results for the triangular probability density function are constrained to the range  $1.342... < T_{90}/T_{50} < 2.335...$ , and are virtually coincident with the results for the weibull probability density function. This makes the former difficult to see in Figure 5

### 3.3 TIMING OF INTERVENTIONS

There is no requirement for interventions to occur on equal intervals. However, characterization of the net intervention efficiency is easiest when the interval size is constant.

Figure 6 shows how the net intervention efficiency varies with the intervention interval. The intervention interval,  $\Delta t$ , is normalized by the characteristic time,  $T_{50}$ . The results illustrate that more frequent intervention ( $\Delta t \rightarrow 0$ ) results in greater net intervention efficiency, as would be expected.

Most surprisingly, Figure 6 shows that the net intervention efficiency has almost no dependence on probability density function. While not invariant in a true mathematical sense, net intervention efficiency appears to be invariant with probability density function in a practical sense.

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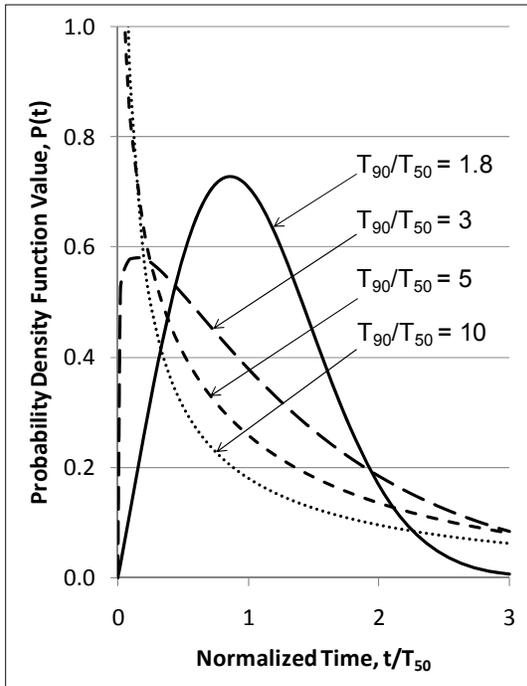


Figure 4. The influence of skewness ratio on the Weibull probability density function.

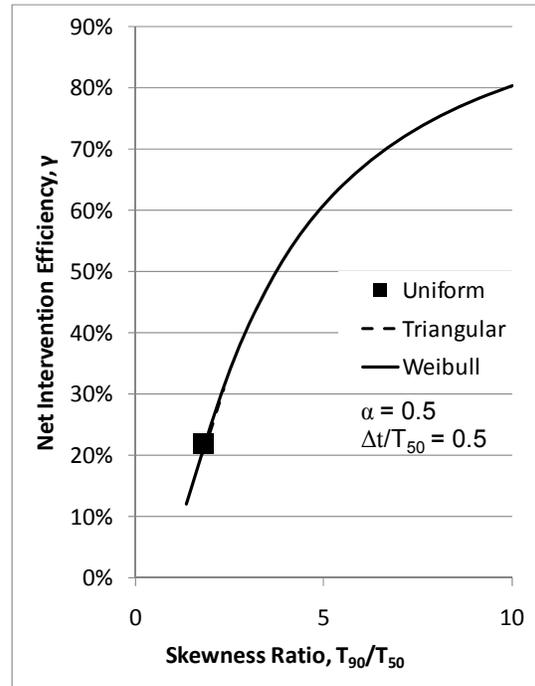


Figure 5. Dependence of net intervention efficiency on skewness ratio of the probability density function.

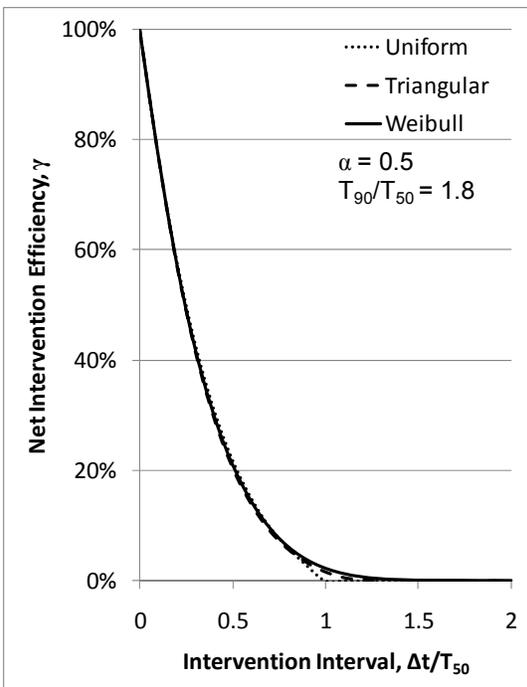


Figure 6. Dependence of net intervention efficiency on intervention interval.

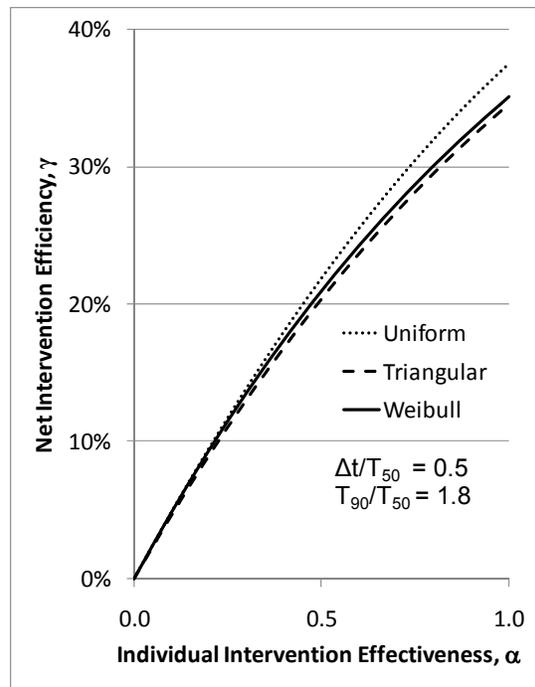


Figure 7. Dependence of net intervention efficiency on individual intervention effectiveness.

## 3.4 INDIVIDUAL INTERVENTION EFFICIENCY

Figure 7 shows that the net intervention efficiency is very dependent on the effectiveness of the individual interventions, as would be reasonably expected. If the individual interventions are totally ineffective ( $\alpha = 0$ ), then the net intervention effectiveness is also 0. So:

$$\lim_{\alpha \rightarrow 0} \gamma = 0 \quad (15)$$

## 3.5 COMBINATION OF ALL CONTROLLING PARAMETERS

Figure 5 shows that the net intervention effectiveness is very dependent on the skewness ratio,  $T_{90}/T_{50}$ . In order to have a useful predictive tool, the variation of  $\gamma$  with  $\alpha$ ,  $\Delta t$ , and  $T_{50}$  must be available for various values of  $T_{90}/T_{50}$ . Table 2 provides that data for the range  $1.8 \leq T_{90}/T_{50} < 5.0$ , which covers the range of the majority of practical applications.

All values in Table 2 are derived from simulations using the weibull probability density function. The values in the tables can be interpolated for intermediate values of  $\alpha$ ,  $\Delta t/T_{50}$ , and  $T_{90}/T_{50}$ .

## 4. A WORKED EXAMPLE

Consider the following:

- A business process is in place whereby approvals are electronically requested from a manager-level person at a given company.
- The current business process configuration is such that no reminders are sent to tardy approvers.
- The electronic system, perhaps a workflow management system, tracks when approvals are accomplished, and this data is available for analysis.
- The wait times are calculated, being the difference between the approval timestamp and the approval request timestamp. Only 8 working hours per calendar day are taken into account.
- The median wait time  $T_{50} = 20$  hr.
- The time when 90% of the approvals are complete is  $T_{90} = 36$  hr.
- The average wait time  $\bar{t}_0 = 21.2$  hr. Note that the median time and the mean time are generally not equal.

The organization wishes to accelerate the approvals, by instituting a daily reminder for tardy approvals. How much will the approvals be accelerated, if approvers are likely to respond to about one-half of the reminders? That is:

- $\Delta t/T_{50} = 8/20 = 0.4$
- $\alpha = 0.5$

From Table 2,  $\gamma = 0.2994$ .

From Equ. (13),  $\bar{t}_\alpha = \bar{t}_0(1 - \gamma) = 21.2(1 - .2994) = 14.85$  hr

That is, using the parameters as described in the problem description, the average wait time will be reduced from 20 hr to 14.85 hr.

## 5. DISCUSSION

This research begins with the representation of wait times using a probability distribution. Electronic systems have the ability to issue reminders or notifications to individuals, if a task assignee is tardy in completing the task. If the reminders are even somewhat effective (i.e.  $\alpha > 0$ ), this has the effect of distorting the shape of the probability distribution, albeit in a predictable manner.

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The improvement in business process performance is measured using the net intervention efficiency,  $\gamma$ , defined in Equ. (13). However, Equ. (13) uses the derivation of Equ. (12), which contains integrals of the probability density function  $P(t)$ . These integrals are problematic since (a) there may be no closed-form integral for the relevant probability density function, and, (b) generally, the probability density function may not even be known. So, to use Equ. (13) in practice, it's necessary to either approximate the values in Equ. (12) using numerical integration (such as the Runge-Kutta method), or to simulate the business process using a technique such as the Petri Net method. This author has chosen the latter, since it is more generally applicable to business process analysis. Petri Net models of the relevant business processes were created and the results compared with known closed-form solutions for the simpler probability density functions, such as the uniform distribution and the triangular distribution. A sufficient number of iterations was performed ( $10^7$ ) to ensure convergence of the results to one part in  $10^4$ , or 0.01%. Thus validated, the model was then redeployed to solve for cases where there is no known closed-form solution.

By comparing the results for uniform, triangular and weibull probability density functions, it became apparent that there is little dependence in performance on the choice of probability density function. This probability density function invariance may be the most important outcome of this research, since, in practice, wait times will have some probability distribution, but not necessarily one that can be easily characterized. If the business process improvement is invariant with probability density function, then the results from this paper (largely determined using the weibull probability density function) would be applicable to all cases.

The skewness of the probability density function has a large impact on the net intervention efficiency. The greater the skewness, the greater the performance improvement that interventions will provide. This is reasonable since a more highly skewed probability density function has a greater portion of events along the extended tail of the distribution. If these events can be accelerated, due to intervention, then the average wait time drops substantially. For example, an event that used to have a 100 hr wait time which is reduced to 20 hr, has a much greater effect on the average wait time than an event that used to have a 30 hr wait time which is reduced to 20 hr due to intervention. One challenge, when putting this concept into practice, is measuring the skewness. There is indeed a formal mathematical definition of skewness. This author has chosen not to use it due to the difficulties associated with calculating the skewness from sets of real data. Instead, this paper uses a different measure of skewness, termed the "skewness ratio", which is simply the ratio of  $T_{90}$  vs.  $T_{50}$ . Both  $T_{90}$  and  $T_{50}$  can be determined via inspection of a sorted data set, so there's little effort in determining the skewness ratio, and no debate about which probability density function is the "correct" one for a given application.

The timing of the interventions, termed the "intervention interval", has a significant effect on the net intervention efficiency. One can draw the following conclusions from Figure 6: (a) interventions that occur less frequently than the medium time (i.e.  $\Delta t/T_{50} > 1$ ) have little impact on the net intervention efficiency, but will have positively influence very late events (i.e.  $\Delta t/T_{50} > 2$ ), and, (b) significant improvements in net intervention efficiency occur in the range  $\Delta t/T_{50} < 0.5$ . From a practical perspective, if  $T_{50} = 2$  days, then sending daily reminders ( $\Delta t/T_{50} = 0.5$ ) would provide a benefit. However, if  $T_{50} < 2$  days, then the reminders would be more frequent than once a day, and such a high frequency of reminders would be perceived as burdensome by the reminder recipient. There is an increasing risk that all reminders would be ignored by the recipient, as the intervention interval tends to zero. A general guideline therefore would be that, "if the median wait time for an event is greater than 2 days, then reminders will likely be effective; if the median wait time is less than 2 days, then using reminders as an intervention strategy will not likely be effective".

Note also that Figure 6 provides further evidence of the observation that net intervention efficiency is invariant with choice of probability density function.

## Quantifying the Effectiveness of Interventions in Workflows

$T_{90}/T_{50} = 1.8$		Tabulated values are net intervention efficiency, $\gamma$								
$\alpha$	$\Delta t/T_{50}$									
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0%	-	-	-	-	-	-	-	-	-	-
10%	0.3861	0.2012	0.1200	0.0757	0.0492	0.0316	0.0201	0.0128	0.0076	0.0046
20%	<b>0.5693</b>	0.3420	0.2179	0.1425	0.0940	0.0617	0.0399	0.0251	0.0152	0.0091
30%	<b>0.6694</b>	0.4430	0.2977	0.2015	0.1359	0.0903	0.0588	0.0371	0.0228	0.0131
40%	<b>0.7305</b>	<b>0.5175</b>	0.3635	0.2535	0.1744	0.1175	0.0772	0.0491	0.0301	0.0177
50%	<b>0.7708</b>	<b>0.5741</b>	0.4183	0.2994	0.2101	0.1437	0.0957	0.0611	0.0373	0.0220
60%	<b>0.7992</b>	<b>0.6175</b>	0.4642	0.3402	0.2428	0.1681	0.1130	0.0725	0.0449	0.0266
70%	<b>0.8201</b>	<b>0.6517</b>	<b>0.5027</b>	0.3765	0.2735	0.1918	0.1298	0.0841	0.0520	0.0307
80%	<b>0.8361</b>	<b>0.6792</b>	<b>0.5354</b>	0.4087	0.3014	0.2142	0.1462	0.0952	0.0595	0.0349
90%	<b>0.8487</b>	<b>0.7016</b>	<b>0.5632</b>	0.4374	0.3274	0.2354	0.1621	0.1062	0.0664	0.0391
100%	<b>0.8589</b>	<b>0.7203</b>	<b>0.5872</b>	0.4630	0.3515	0.2555	0.1774	0.1172	0.0733	0.0434

$T_{90}/T_{50} = 3.0$		Tabulated values are net intervention efficiency, $\gamma$								
$\alpha$	$\Delta t/T_{50}$									
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0%	-	-	-	-	-	-	-	-	-	-
10%	<b>0.5306</b>	0.3404	0.2393	0.1775	0.1360	0.1069	0.0855	0.0693	0.0561	0.0467
20%	<b>0.6870</b>	<b>0.5004</b>	0.3788	0.2949	0.2345	0.1886	0.1537	0.1264	0.1043	0.0865
30%	<b>0.7608</b>	<b>0.5923</b>	0.4700	0.3789	0.3084	0.2533	0.2098	0.1741	0.1459	0.1223
40%	<b>0.8036</b>	<b>0.6521</b>	<b>0.5341</b>	0.4409	0.3662	0.3056	0.2566	0.2156	0.1815	0.1541
50%	<b>0.8315</b>	<b>0.6940</b>	<b>0.5815</b>	0.4889	0.4127	0.3489	0.2959	0.2511	0.2135	0.1816
60%	<b>0.8512</b>	<b>0.7247</b>	<b>0.6176</b>	<b>0.5271</b>	0.4504	0.3849	0.3296	0.2820	0.2412	0.2067
70%	<b>0.8657</b>	<b>0.7482</b>	<b>0.6464</b>	<b>0.5582</b>	0.4817	0.4156	0.3585	0.3088	0.2663	0.2294
80%	<b>0.8769</b>	<b>0.7671</b>	<b>0.6698</b>	<b>0.5839</b>	<b>0.5083</b>	0.4419	0.3839	0.3328	0.2884	0.2498
90%	<b>0.8858</b>	<b>0.7823</b>	<b>0.6890</b>	<b>0.6055</b>	<b>0.5312</b>	0.4650	0.4063	0.3545	0.3087	0.2687
100%	<b>0.8931</b>	<b>0.7947</b>	<b>0.7052</b>	<b>0.6239</b>	<b>0.5506</b>	0.4849	0.4259	0.3735	0.3268	0.2855

$T_{90}/T_{50} = 5.0$		Tabulated values are net intervention efficiency, $\gamma$								
$\alpha$	$\Delta t/T_{50}$									
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0%	-	-	-	-	-	-	-	-	-	-
10%	<b>0.6823</b>	<b>0.5199</b>	0.4162	0.3446	0.2905	0.2495	0.2172	0.1905	0.1686	0.1510
20%	<b>0.7964</b>	<b>0.6630</b>	<b>0.5649</b>	0.4892	0.4289	0.3792	0.3377	0.3025	0.2733	0.2465
30%	<b>0.8455</b>	<b>0.7330</b>	<b>0.6445</b>	<b>0.5719</b>	<b>0.5118</b>	0.4607	0.4168	0.3784	0.3454	0.3159
40%	<b>0.8731</b>	<b>0.7749</b>	<b>0.6942</b>	<b>0.6260</b>	<b>0.5679</b>	<b>0.5171</b>	0.4728	0.4333	0.3985	0.3675
50%	<b>0.8909</b>	<b>0.8029</b>	<b>0.7287</b>	<b>0.6644</b>	<b>0.6085</b>	<b>0.5589</b>	<b>0.5150</b>	0.4752	0.4400	0.4078
60%	<b>0.9033</b>	<b>0.8231</b>	<b>0.7540</b>	<b>0.6931</b>	<b>0.6394</b>	<b>0.5912</b>	<b>0.5480</b>	<b>0.5088</b>	0.4731	0.4408
70%	<b>0.9125</b>	<b>0.8384</b>	<b>0.7734</b>	<b>0.7157</b>	<b>0.6638</b>	<b>0.6170</b>	<b>0.5744</b>	<b>0.5355</b>	<b>0.5004</b>	0.4678
80%	<b>0.9196</b>	<b>0.8503</b>	<b>0.7888</b>	<b>0.7336</b>	<b>0.6835</b>	<b>0.6381</b>	<b>0.5964</b>	<b>0.5583</b>	<b>0.5227</b>	0.4906
90%	<b>0.9252</b>	<b>0.8599</b>	<b>0.8013</b>	<b>0.7483</b>	<b>0.7000</b>	<b>0.6557</b>	<b>0.6146</b>	<b>0.5770</b>	<b>0.5424</b>	<b>0.5101</b>
100%	<b>0.9298</b>	<b>0.8678</b>	<b>0.8118</b>	<b>0.7606</b>	<b>0.7138</b>	<b>0.6705</b>	<b>0.6305</b>	<b>0.5934</b>	<b>0.5589</b>	<b>0.5270</b>

**Table 2. Dependence of net intervention efficiency on intervention interval and individual intervention effectiveness, for various values of skewness ratio.**

## Quantifying the Effectiveness of Interventions in Workflows

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Figure 7 shows that the effectiveness of an individual intervention (i.e. a single reminder) has a significant impact on the net intervention efficiency. Many factors influence the individual intervention effectiveness. Those that tend to decrease  $\alpha$  include:

- the intervention recipient is “too busy” with other things,
- the recipient has some knowledge of the proposed task and decides that there are other higher priority tasks that s/he must attend to, and,
- the recipient is away from his desk/computer or other means for accessing emails, therefore doesn't receive the notifications when they are transmitted.

Factors that tend to increase  $\alpha$  include:

- the converse of the 3 previous bullet points,
- Management expectation that each person will perform his/her when assigned, and only rarely receive reminders. If only a single reminder is issued, after time  $\Delta t$ —this single reminder may be treated more seriously than a series of periodic reminders,
- Management rules whereby a task is assigned, and a single reminder is issued after time  $\Delta t$ . If the task is not performed by time  $2\Delta t$ , then the task is removed from the original assignee, and escalated to that person's supervisor.

Relating  $\alpha$  to the aforementioned factors really deals with psychology. So Figure 7 accurately portrays the  $\alpha - \gamma$  relationship, but does not quantify the factors governing  $\alpha$ .

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