Simulating Email Flow within Knowledge Networks

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Abstract. This study describes a model that simulates the flow of email within a network of knowledge workers. Such a model could be utilized to understand several aspects of information exchange at the network or individual level such as communication effectiveness, task completion time, email response time, etc. and help identify time based email processing strategies that can foster productive utilization of time at work, which is a constrained resource. The simulation model can help devise coping mechanisms to mitigate two important managerial problems, information overload and interruptions associated with emails. These issues are easier to explore through simulation rather than by using alternate approaches such as field study, lab experiments, etc. We discuss the need for developing such a model and describe various analytical and logical components of the model. Finally, important implementation aspects of this model are explained.

Keywords: Email Management, Networks, Interruptions, Performance.

1 Introduction

Email has become the most prevalent mode of business communication and information exchange within organizations and has changed the way we spend our time at work. It provides a cost-effective and open medium for sharing information and improves time-effectiveness and efficiency [1]. However, several recent scientific and anecdotal reports are starting to recognize the enormous amounts of time being spent interacting through emails at work. While this excessive interaction has produced some good outcomes such as increased productivity, faster information exchange etc., it has, at the same time, spawned some side effects such as email overload, interruptions, technology addiction, attention deficiency, productivity loss, etc. [2]. Several different approaches can be taken to address many of these problems. However, it is not the technology that will provide the solution; it is the improvement in new email management practices that is needed to solve these problems [3].

This study focuses specifically on two major problems: information overload and interruptions caused by email use within organizations. There is a reported lack of research on effective email management within organizations to deal with these problems, and only a few studies have focused on the various email management strategies (EPS) such as prioritization, classification, timing and frequency of email processing, etc. The implementation of these email management strategies could have the potential to not only improve the way we deal with our emails but also make the knowledge workers' overall workday more productive.

Nowadays, workers are overwhelmed by the enormous quantities of emails they receive [4]. In order to cope with the increasing number of emails, they continually check for newly arrived emails or focus on immediate processing of pending emails, which results in either frequent interruptions [5, 6]. Previous research has shown that interruptions are generally considered to have an ill-effect on performance, and are known to disrupt the routine flow of work [7]. Although the importance of routine has been emphasized in several research studies such as Zellmer-Bruhn [7], the application of any routine or schedule in the processing of emails is still lacking. As a result, senders develop random email processing schedules that lead to increased number of interruptions for senders as well as receivers. This phenomenon becomes even more significant when network aspects are considered. Knowledge workers typically belong to several groups within networks and interact with members of these groups in various capacities depending upon their mutual relationships.

This study describes a simulation model of workflow, comprising of emails and primary tasks, within different types of networks of knowledge workers. Although such networks can differ in several aspects such as density, size, etc., we consider one criterion for the purpose of our model: degree of homogeneity in terms of email processing load of knowledge workers belonging to the network. We classify networks into two types: homogeneous email networks (HEN) and heterogeneous email networks (XHEN) depending upon whether all the knowledge workers within a network have a similar email processing requirements.

Such a model could be used to investigate various time-based scheduling approaches for processing emails within a network. Studies focusing on the issue have reported varied findings with no consensus on the optimal email processing strategy. For example, a study conducted by Jackson et al. [6] suggests that knowledge workers should process emails every 45 minutes (approximately eight times a day). Another study reported that processing emails once a day is the best strategy [8]. Findings of these studies were challenged by the results reported in two recently conducted studies [9-11], which suggest that processing emails two to four times a day is the best strategy. All of, these studies were conducted at an individual level. The models presented in this paper could be used for conducting a comparative performance analysis of these policies at a network level. Further, these models will help towards the quantification of the impact of various email processing strategies on the overall effectiveness of communication. A few studies have reported the negative impact of emails on productivity [4] but have not quantified it.

The paper is divided into four sections. Next section provides a brief review of literature of research on emails and interruptions. The following section explains the theoretical and analytical development of the simulation model, leading to the section that describes the implementation logic of the model. Finally, some of the limitations of the model and implications for future research are presented along with some concluding remarks.

2 Literature Review

Network approaches have proved to be tremendously useful in modeling the information flow within the real-world organizations by making certain a-priori assumptions. Such assumptions make the problem tractable and help observe a complex phenomenon such as flow of information within a work environment. Huberman and Adamic [12] and Wu and Huberman et al. [13] studied information flow in groups using network analysis approaches. Several other studies on emails have taken a different viewpoint. Ahuja and Carley [14] studied the impact of different network structures such as centralization, degree of hierarchy, levels of hierarchy, and different task characteristics such as analyzability and variety on the network performance. Johnson and Faraj [15] built an entire simulation model of a knowledge network to understand the role of preferential attachment and mutuality in network formation. Some studies have aimed to reduce the overload in a networked environment such as virtual groups, social spaces such as UseNet, and email distribution lists. Sharda et al.[16], for example, studied the phenomenon of information overload for group knowledge networks and made several propositions to help reduce the overload for the entire network. Another field study tried to understand how the volume of communication is associated with message complexity in large social spaces [17]. However, none of these studies looked at EPS.

2.1 Interruptions

Jackson and colleagues conducted a few studies to understand the cost of email interruptions in organizations [6, 18]. They found that the overall interruption effect of email is greater than that caused by phone calls, and reported several important parameters on the time lags created due to these interruptions resulting from emails. They found that it takes an average of one minute and forty-four seconds to react to a new email by activating the email application. The time needed to switch from a current work medium to the email medium is often referred to as *switching time* or *interruption lag* [19]. A knowledge worker spends extra time to restart a task interrupted by email due to re-immersion. The recovery time due to interruptions caused by email is also referred to as *resumption lag* [19]. This penalty has been reported to be about 64 seconds per interruption [6, 18]. According to these authors, although this time may appear to be small, the cumulative interruption and resumption lags become significant due to the large number of messages arriving every day. These lags have the potential to increase the non-value-added time spent by a knowledge worker and thereby decrease their time-effectiveness. Figure 1 describes the generic process of interruptions graphically. When an interruption arrives, a knowledge worker is preempted from a primary task. After spending a small *interruption lag (IL)*, the worker starts to process the interrupt. Once the processing on the interrupt is over, workers spend a small *resumption lag (RL)* before they can resume their previously interrupted task. A few other studies have tried to evaluate *RL* either quantitatively or qualitatively[20-22]. We modified versions of formulae presented by Ash and Smith-Daniels [20] and apply them to develop further understanding about interruption losses due to email at a network level.

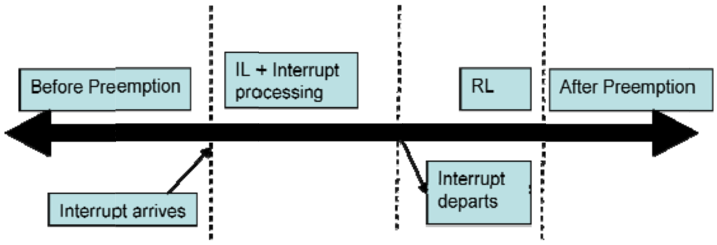


Figure 1. The Process of Interruption [19]

3 Simulation Model

We model a network comprising of three knowledge workers interacting with each other as well as with the outside world, which collectively represents a group of knowledge workers not belonging to the network and processing emails at random times of the day. Figure 2 describes the flow of email within this network. We recognize that most knowledge networks contain more than three workers, but the smaller number allows us to explain the concepts clearly while permitting the needed diversity. Each worker in this model could represent many similar workers.

We model two types of networks: *homogeneous email networks (HEN)* and *heterogeneous email networks (XHEN)*. These networks are classified based on whether the email processing load of knowledge workers within a network is similar or not. As described earlier, a *"homogeneous email network" (HEN)* has all the knowledge workers with a similar email processing load whereas, a *heterogeneous email network (XHEN)* has knowledge workers having different email processing loads. HEN types of network typically exist where hierarchies may not be present. Examples include networks that are involved in brainstorming, idea generation, etc. We may also see such networks in flat hierarchical organizations, clubs, networks of friends, etc. On the other hand, in XHEN networks, certain knowledge workers have a higher need for exchanging emails than other workers. For example, a network in hierarchical organizations has workers at different levels having different needs for email processing. In following sub-sections, we describe the theoretical and analytical development of different modules of the simulation model.

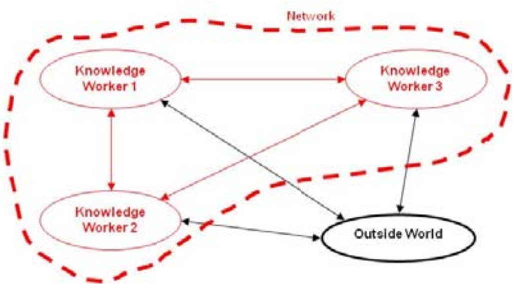


Figure 2. Email Flow within a Network

3.1 Modeling Emails

All the emails that are received can be broadly classified into two main types, ones that elicit a response from the recipient and those that don't require a response from the recipient (For Your Information- FYI- represented by F). Although email messages may be grouped in many different ways, we use the following definition to classify them. Emails that require a response can further be classified into two types based upon the time it takes to process them: complex emails (C) and simple emails (S). Complex emails require a relatively longer time to process, whereas simple emails require a short time to process. These categories of emails, represented by '*k*', can have any of the three values, C, S, and F.

Each type of email undergoes a cycle of processing before it gets resolved. The length and nature of this cycle depends upon the type of email i.e. whether the email requires a response or not. Emails that require a response by the receiver go through three phases of processing (represented by '*l*') before they are resolved. An email during its first processing stage (l=1) has been created or processed by the sender and sent to the receiver. As soon as this email reaches the receiver, it enters its second processing phase (l=2). After waiting for a certain time period, the receiver will begin processing this email. This processing may involve reading the email, creating a response, and sending it back to the original receiver. As soon as this email response reaches the original sender, the email enters its third stage of processing (l=3). During this last stage of processing, the original sender reads the email, extract the necessary information and file it away in the inbox. The emails that do not elicit any response from the receiver have a short message thread life as they undergo only two stages of processing. During phase one, such emails are created by the sender and sent to the receiver. In the second phase, the receiver extracts the information contained in the email and takes the necessary action to resolve it. This may include deleting the email or filing it away but it does not require the receiver to generate a response to be sent to the original sender. It usually takes a relatively small time to process such emails. Figure 3 (a, b) explains the sequential processing phases of different types of emails.

Figure 3 (a). Email Processing Phases that Require Response

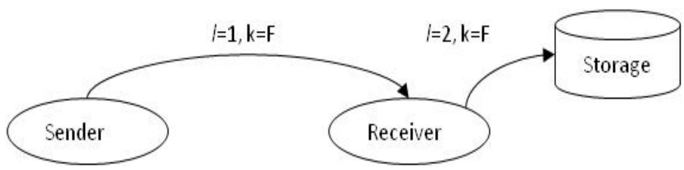


Figure 3 (b). Email Processing Phases that Do Not Require Response

The processing cycle is relatively small if the email is of type F, such as FYI emails, informative emails, notification email, CC emails, listserv emails, etc. Type F emails do not require a response to the original sender and tend to be resolved once they have been processed by the receiver. This cycle will be relatively long if the email is a type C or S that requires the receiver to respond to the original sender. For such emails, the cycle ends after the response from the receiver has been processed by the email's original sender. This also marks the resolution of the email. We recognize that many emails are much longer threads, but this thread can be assumed to consist of many pairs of email exchanges.

The processing time for an email in the different phases is different as well. A survey of a convenience sample of email users in several large companies [23] revealed that processing an email usually takes longer in the second phase than in the first or third processing phases.

It is important to note here that the focus of the model is on email resolution and not issue resolution. An email resolution does not guarantee the resolution of the issue discussed in the email, when it undergoes one cycle of processing. An issue being discussed over email often requires more than one cycle to be resolved. Our focus in this model is not on issue resolution but on email processing times, so we only model email exchanges in pairs or single email processing.

3.2 Modeling Email Life

An interesting stream of research focused on understanding the value that an organization derives from communicating in a network [24, 25]. However, none of these studies have specifically looked at how the value of information contained in an email varies with the time for which it remains unresolved. The life of any email can be said to comprise three phases. During the first phase, the value of the email remains constant. An email provides maximum value to the network if it is processed while still in the first phase. Its value starts to diminish at a particular rate beyond phase one time period. Emails processed during their "second" phase result in a positive value that is less than the maximum but greater than zero. After this phase, an email reaches its third phase, where any action taken on the email does not provide any value to the network. This implies that the life of an email could be modeled based on a curve that approximates a sigmoid function but with differing shapes that are determined by the urgency level of the email.

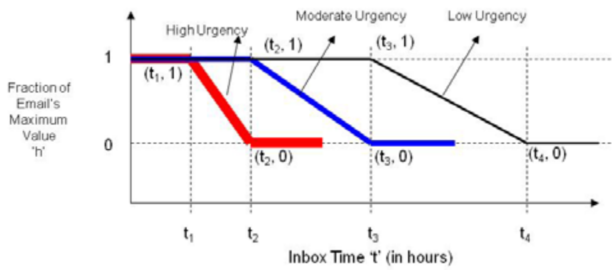


Figure 4. Email Value vs. Email Life for High, Moderate and Low Urgency Emails

These email values are modeled as follows, based upon our observation of hundreds of emails over one year, we classify all email into three major categories based on their urgency level: emails with high urgency, emails with moderate urgency, and emails with low urgency. Emails with high urgency demand a quick response from the recipient, as their value to the organization falls very quickly. On the other extreme are the emails with low urgency. Such emails require a rather slow response and usually have a longer life time. Between the two extremes lie emails with moderate urgency. Figure 4 shows the life cycle of three types of email.

If highly urgent, moderately urgent and low urgent emails are responded to within t_1 hours, t_2 hours, t_3 hours respectively, then organizations derive maximum value from the information contained in the email. On the other hand, if highly urgent, moderately urgent and low urgent emails are responded after t_2 hours, t_3 hours, t_4 hours respectively, than organizations derive no value from the information contained in the email. If instead a highly urgent email is processed anytime during $(t_2 - t_1)$ hours, a moderately urgent email is processed anytime during $(t_3 – t_2)$ hours, and a low urgent email is processed anytime during $(t_4 – t_3)$ hours, than the value derived depends on a negative linear function having same intercept but different slope. Using simple co-ordinate geometry concepts, we can easily derive the equations for all three straight lines. Equation (1) can be used to derive value for highly urgent emails.

$$h = \left(\frac{1}{(t_2 - t_1)} \right) * \left(t + t_2 - 2t_1 \right). \qquad \text{Where, t is in hours} \qquad \textbf{(1)}$$

Similarly, we can find the value derived by from moderate and low urgency emails. Our observation of hundreds of emails leads us to believe that $(t_2 - t_1) < (t_3 – t_2) < (t_4 – t_3)$.

3.3 Modeling Email Processing Strategies (EPS)

According to the Single-Resource theory [26], frequently diverting resources such as the attention of a knowledge worker to a secondary task (email) decreases the performance on the primary task. This suggests that by segregating the time during which interruptions and interrupted tasks are given higher priority for processing, we could potentially reduce the interaction between interruptions and interrupted tasks. Thus, controlling the timeframe within which an email is allowed to interrupt can reduce the number of interruptions, thereby reducing the cumulative switching (IL) and recall time (RL) and improving the performance on primary tasks. Such time-based controls also allow for better attention allocation, which is a scarce resource in modern organizations [27].

To establish such a timeframe, we introduce the notion of "*email priority hour*" and "*task priority hour*." The overall knowledge work hours in a particular workday can be split into two categories: one during which email is given the highest priority, termed *"email priority hour,"* and the other during which primary tasks are given the highest priority, termed "*task priority hour*." All the email processing strategies have the same overall *email priority hour* length per work day (T_N) for a particular knowledge worker, but they differ in terms of the total number of such email hour slots (Ω) and length of each email hour slot (τ) within each policy. The overall email hour length (T_N) is a product of the number of email hour slots (Ω) and the length of each email hour slot (τ). For a network comprising "*N*" number of knowledge workers, the total length of email priority hours is given by:

$$T_{EPS} = \sum_{i=1}^{N} (T)_i = \sum_{i=1}^{N} (\Omega_i \times \tau_i). \qquad (2)$$

Where, "i" represents a particular knowledge worker.

The value of T_N signifies the total time for which a knowledge worker prioritizes email processing per work day. Variations in the value of T_N also represent different types of knowledge workers depending upon the extent of their email processing requirements. Using the statistics reported in a survey conducted by American Management Association (2004), we classify knowledge workers in four different categories based on their dependency on email communication: very high users of email, high users, low users, and very low users. "Very high" users spend an average of four hours per workday processing email (T_N = 4 hrs.), "high" users spend three hours (T_N = 3 hrs.), "low" users spend two hours (T_N = 2 hrs.) and "very low" users spend one hour (T_N = 1 hr.). Different combinations of "Ω" and "τ" values lead to different EPSs. For a particular type of knowledge worker (either low or high users of email), the different EPSs that we compare have same values of T_N but differ in terms of the values of Ω and τ .

Under the C1 policy, knowledge workers process their email in a single batch. Thus, it comprises one email hour slot (Ω = 1) of length 2 hours (τ = 2) for low users of email and 3 hours for high users of email ((τ = 3). On the other hand, the C policy represents continual processing of emails, i.e. emails are processed as soon as they arrive. A knowledge worker working on a primary task keeps up with the flow of incoming messages by processing them immediately, as the C policy is adopted.

Four other variations of EPSs are considered when the processing of email is scheduled at particular times of the day. In the C2 policy, the entire length of email hours is divided into two time slots (Ω = 2). In the C4 policy, email hours are split into four time slots of equal duration (Ω = 4). C6 has six email hour slots. Processing email every 45 minutes is approximately equivalent to eight email-hour slots. C8 is suggested as the best policy by Jackson et al.[6]. In other words, EPSs ranging from C1 to C represent the complete range of all processing strategies that can be used by any knowledge worker. One thing that we will note with all these policies is that as the number of email-hour slots (Ω) increases, the time-length of each slot (τ) decreases, and that ultimately brings an EPS closer to the continual policy (C).

3.4 Modeling Email Flow and Interruption Process

Figure 5 describes the flow of emails and shows how EPS are used to manage interruptions and reduce overload within any work environment. A new email created by the sender reaches the recipient, but the processing of this email begins only after several conditions have been met. The first is whether email priority hours are in progress or not. If email priority hours are in progress and there are pending emails, than there will be a delay in the processing of this new email. Once the queue of all pending email clears up, the knowledge worker may begin processing the new email.
If the email queue is zero and email priority hours are underway, any processing of the primary task will be interrupted, interruption lag will occur due to the switching involved, and processing on the new email will begin. Resumption lag time will be added before any work on the primary task is resumed. The future course of this email depends on whether it requires a response of not. An email requiring a response will go through a similar pattern but this time at the sender’s end. The email not requiring a response will be stored in the inbox. Instead, if task priority hours are in-progress and the recipient is also busy with primary-task processing, the email will wait until the arrival of next scheduled email hour or the completion of the primary task, whichever occurs first.

Each network can comprise several groups that may or may not have an overlap. Assuming that there is no overlap in the group, we now describe the mathematical formulations for evaluating IL and RL. Let,

$N(g) \rightarrow$ Total number of knowledge workers belonging to g^{th} group in the network

$G \rightarrow$ Total number of groups in the network

$D \rightarrow$ Total number of days for which observation is made

$M \rightarrow$ Total number of tasks performed per day

Below, we describe different component of time spent by i^{th} knowledge worker belonging to g^{th} group on d^{th} day,

$T_O(i,d,g) \rightarrow$ is the total units of time spent (value added + non-value added)

$T_v(i,d,g) \rightarrow$ is the actual units of time spent (value-added component of time) on processing primary tasks and emails.

$T_\psi(m,i,d,g) \rightarrow$ is the overall non-value-added component of $T_O(m,i,d,g)$ and represents the total non-value-added time spent during the completion of m^{th} task

$T_v^1(e,i,d,g) \rightarrow$ is a component of $T_v(e,i,d,g)$ and is the total value-added time spent on processing emails until the completion of e^{th} email.

$T_v^2(m,i,d,g) \rightarrow$ is a component of $T_v(i,d,g)$ and is the total value-added time spent on processing primary tasks until the completion of m^{th} task.

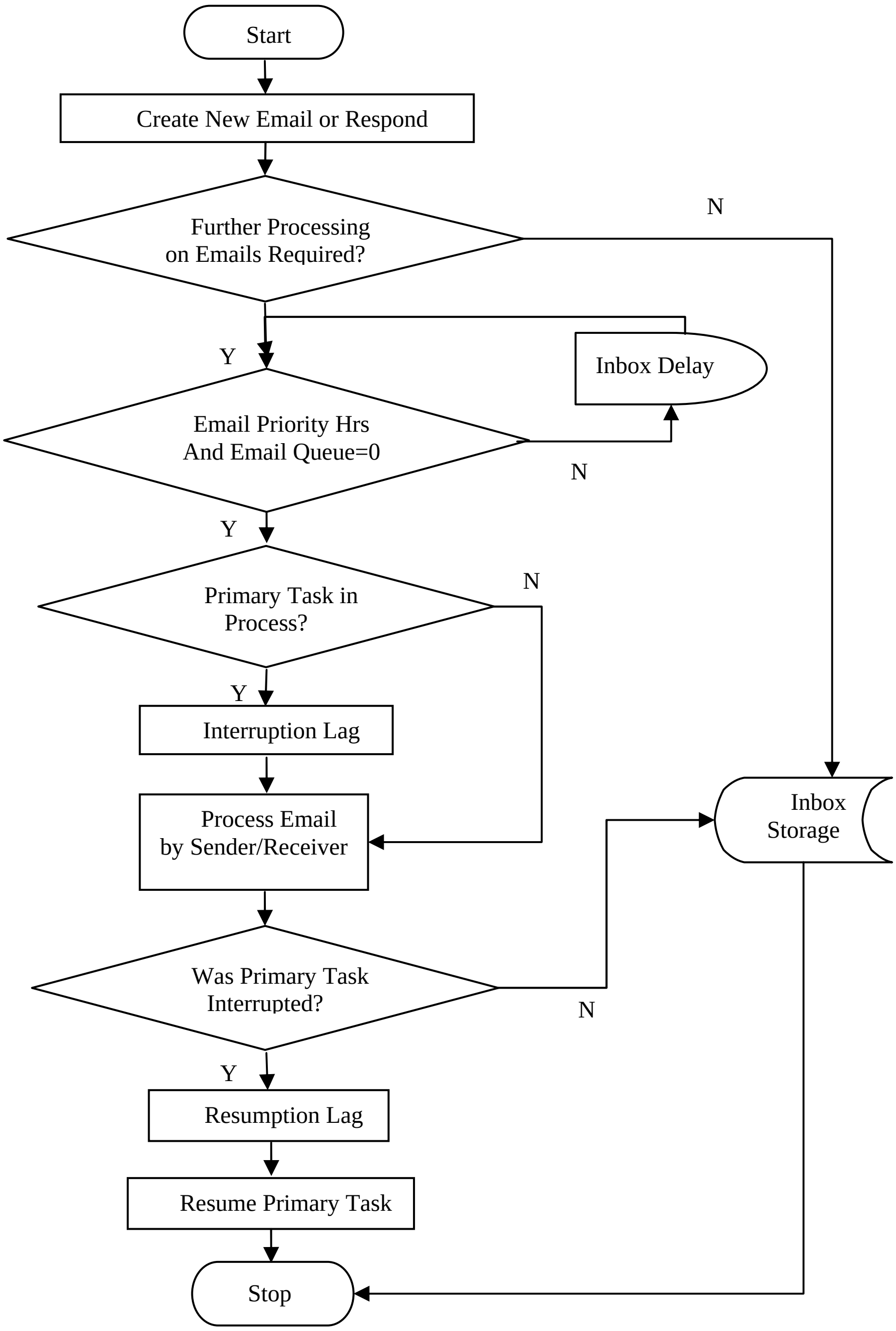


Figure 5. Flow of Email and Managing Interruption using Email Processing Strategies

$T_f(m,i,g,d) \rightarrow$ is a component of $T_O(i,d,g)$ and comprises times spent on processing emails and time spent on interruption lag. It is defined as the time attributed to the forgetting of m^{th} task.

$T_\psi^1(m,i,g,d) \rightarrow$ is a component of $T_\psi(m,i,d,g)$ and is the total non-value-added time spent due to interruption lag until the completion of m^{th} task.

$T_\psi^2(m,i,d,g) \rightarrow$ is a component of $T_\psi(m,i,d,g)$ and is the total non-value-added time spent due to recall lag until the completion of m^{th} task.

$T_\psi^2 \rightarrow$ is the total resumption time spent by the entire network in D number of days and is the summation of $T_\psi^2(m,i,d,g)$ for D number of days.

The total time spent by all the knowledge workers belonging to a network on any given day is the summation of total value-added and non-value-added times spent by the knowledge worker. Each of these components has two subcomponents. The value-added time that knowledge workers actually spend on performing the work, i.e., $T_v(i,d,g)$ comprises the time spent on processing emails, i.e. $T_v^1(e,i,d,g)$ and primary tasks, i.e. $T_v^2(m,i,d,g)$. On the other hand, the non-value-added time i.e. $T_\psi(m,i,d,g)$ comprises time accounted for by interruption lag denoted by $T_\psi^1(m,i,g,d)$ and resumption lag denoted by $T_\psi^2(m,i,d,g)$. Since, the work environment of a knowledge worker usually involves some time-based learning. In such an environment, proficiency of the worker on primary task improves as amount of time spent on the task increases. However, during the time when an interrupt is being processed, forgetting also occurs and that leads to a loss of proficiency [20, 22].

Only two of our four basic subcomponents of time contribute towards the forgetting of a primary task, namely the time spent on processing emails $T_v^1(e,i,d,g)$ and the interruption lag time $T_\psi^1(m,i,g,d)$. These two subcomponents, when added, give the total time for which forgetting occurred, i.e. $T_f(m,i,g,d)$. The expression below describes it mathematically,

$$T_O(i,d,g) = T_v(e,i,d,g) + T_\psi(m,i,g,d) \quad (3)$$

$$= \left(T_v^1(e,i,d,g) + T_v^2(m,i,d,g)\right) + \left(T_\psi^1(m,i,g,d) + T_\psi^2(m,i,d,g)\right)$$

$$= T_v^2(m,i,d,g) + \left(T_\psi^1(m,i,g,d) + T_v^1(e,i,d,g)\right) + T_\psi^2(m,i,d,g)$$

$$= T_v^2(m,i,d,g) + T_f(m,i,g,d) + T_\psi^2(m,i,d,g) \quad (4)$$

Time spent on recalling $T_\psi^2(m,i,d,g)$ depends upon the proficiency levels during different timeframes and the learning rate in the environment [20, 22]. Using Wright's power function [28], Ash and Smith [20] deduced various formulae for proficiency during the learning, forgetting, and relearning (recall) period. These formulae (equations 5 through 8 below) are reproduced from their work after incorporating the network aspects:

$$\mathrm{P}_L(m,i,d,g) = 100\left[1-\left(T_v^2(m,i,d,g)+1\right)^b\right] \quad \mathbf{(5)}$$

Where,

$\mathrm{P}_L(m,i,d,g) \rightarrow$ Proficiency gain at the end of a period before forgetting

$\mathrm{P}_F(m,i,d,g) \rightarrow$ Proficiency level at the end of preemption time (forgetting period)

$\mathrm{P}_R(m,i,d,g) \rightarrow$ Proficiency level at the end of relearning (recall period)

$r_o \rightarrow$ Learning rate of the environment and is a constant that is a characteristic of the intensity with which forgetting occurs in the work environment.

$b \rightarrow$ Wright's power function exponent $b = \log(r_o)/\log(2)$

$$\mathrm{P}_F(m,i,d,g) = \left(\mathrm{P}_L(m,i,d,g)\right)\left(T_f(m,i,g,d)+1\right)^b \quad \mathbf{(6)}$$

$$\mathrm{P}_R(m,i,d,g) = \mathrm{P}_F(m,i,d,g) + \left[\left[100\left(1+[1-r_o]\left[T_f(m,i,d,g)+1\right]^b\right)\right]\times\left[1-\left(T_\psi^2(m,i,d,g)+1\right)^b\right]\right] \quad \mathbf{(7)}$$

Solving the above equation for $T_\psi^2(m,i,d,g)$, we get

$$T_\psi^2(m,i,d,g) = \sqrt[b]{\left\{\left(\mathrm{P}_F(m,i,d,g)-\mathrm{P}_L(m,i,d,g)\right)\Big/\left[100\left(1+[1-r_o]\left[T_f(m,i,d,g)+1\right]^b\right)\right]\right\}+1}-1 \quad \mathbf{(8)}$$

Also, the total time spent due to resumption lag is given by the following expression

$$T_\psi^2 = \sum_{g=1}^{G}\sum_{d=1}^{D}\sum_{i=1}^{N(g)}\sum_{m=1}^{M} T_\psi^2(m,i,d,g)$$

Substituting (8) in the above equation, we get the total value of time lost due to interruptions as

$$= \sum_{g=1}^{G}\sum_{d=1}^{D}\sum_{j=1}^{N(g)}\sum_{i=1}^{M}\left[\sqrt[b]{\left\{\left(p_{Fijdg}-p_{Lijdg}\right)\Big/\left[100\left(1+[1-r]\left[T_{Fijdg}+1\right]^b\right)\right]\right\}+1}-1\right] \quad \mathbf{(9)}$$

Equation (4) and (9) can now be used to calculate the total time spent by the entire network.

4 Model Implementation

This section explains a platform independent implementation of the logical model described in the previous section.

4.1 Implementation of Primary Task Processing

All the knowledge workers that were modeled worked for more than 8 hours per work day and processed their own primary. Knowledge workers did not send their primary tasks to other knowledge workers. The outside world is collectively represented by the fourth knowledge worker within the simulation model. Since the 4^{th} knowledge worker does not process any primary tasks, stochastic task arrival schedules were created for only three knowledge workers using time varying exponential arrival rates. For example, primary tasks do not arrive at night so an arrival distribution for the first 8 hours (starting from midnight) was set to an exponential with zero rate. An arrival rate of Expo (2) was set for the time between 8:00am and 9:00am. HEN network having high email users, where all knowledge workers spend stochastically the same amount of time on primary tasks and emails, uses an arrival schedule that is different from the one used by HEN network with low email users. However, XHEN type of network uses mixed schedules. For every new primary task that is created in the model, the entry time is recorded so that the task completion time can be evaluated when the task was about to exit the system.

The flow of each primary task within the model is regulated by two release conditions. The first condition allows for sequential release of primary tasks to the knowledge workers. The second condition allows a new task to be released only if all the pending or previously interrupted tasks have been processed by the knowledge worker. This is accomplished by constantly monitoring the queue length of primary tasks and the state of knowledge worker. Once a task is released by both conditions, it is ready for processing by the knowledge worker. This resource is seized as soon as a task arrives and is released upon the completion of the primary task, if no interruption occurs during this time. The time spent on the task while it is undergoing processing is recorded as value-added time. However, if an interruption occurs while the knowledge worker is processing the task and an email priority hour is in progress, the knowledge worker is preempted and is diverted to processing emails. The remaining time to be spent on the primary task is recorded in an internal variable (RT), which is then used to evaluate switching time and recall time using formulae described in the previous section. The switching time and recall time both preoccupy the resource and are treated as non-value-added time in the model.

Once the preempted resource is released after processing emails, the knowledge worker begins processing the remaining primary tasks using the previously recorded value of RT. This time is also treated as value-added time by the system. A task can potentially be interrupted several times while undergoing processing. The cycle is repeated each time an interruption occurs and the value stored in the RT variable is updated. As soon as processing on a particular primary task is finished, it leaves the system after various statistics such as the average number of interruptions that occur per day, time spent on each entity, etc. have been calculated and recorded.

4.2 Implementation of Email Processing Strategies

This section explains the logic used to implement various email processing strategies (EPS) within different types of networks. To implement EPS for each knowledge worker, we created a pair of dummy resources, labeled "dummy" and "anti dummy," that do not process any process primary tasks or emails but helped us in identifying when to switch priority between emails and primary tasks. The "dummy" resource is active only during email-priority hours, whereas the "anti dummy" resource remains active only during task-priority hours. The availability of these resources is controlled by the schedule of EPS being used by knowledge workers. So, whenever they are available, their state remains idle since they are not being utilized anywhere and therefore, email priority hours are in progress. On the other hand, if the "anti dummy" is idle, task-priority hours are underway. The model utilizes three such pairs for three knowledge workers belonging to the network.

(STATE (dummy) == IDLE_RES && Email_Process.WIP == 0 && switching.WIP == 0 && relearning.WIP == 0)
(STATE (anti dummy) == IDLE_RES && Primary_Task_Process.WIP== 0 && Primary_Task Reprocess.WIP== 0 && NQ (Hold Primary_Task_Process.Queue) == 0 && switching.WIP == 0 && relearning.WIP == 0)

The above condition comprises two components and determines when an email is released to the knowledge worker for processing. The first part of the condition ensures that emails are released from the hold as soon as they arrive, provided the knowledge worker is not engaged in processing other emails, referred to as work in progress (WIP). This part of the condition also continuously verifies whether the "dummy" agent is idle or not. If the state of "dummy" is idle and the WIP inventory of emails is zero, emails are released for processing or else they wait. The second part of the condition determines how emails are released to the knowledge worker during task-priority hours. An email is released from the hold during task priority hours only if knowledge worker is not processing any other new or previously interrupted primary tasks and no primary task is currently held in any other queue.

4.3 Implementation of Email Flow in the Network

Emails were created in the same way primary tasks were created, using separate schedules, for each of the four knowledge workers. Model assumes that email creation is a need-driven process and therefore does not result in the sender's interruption or lags. Creating an email can also occur when the knowledge worker takes a natural break from working on primary tasks or accomplishes a milestone.

Figure 6 (a and b) shows exponential hourly email creation rates for three knowledge workers and the outside world based on data collected from organizations. As shown in Figure 6 (a), emails are created only during the day time since the three knowledge workers belonging to the network do not work at night, but emails are created by the outside world throughout the day as shown in Figure 6 (b), since knowledge workers outside the network may be located in different time zones around the world. Each of these schedules starts at midnight and is repeated at the beginning of another day. Knowledge workers are not available to process emails during lunch hours.

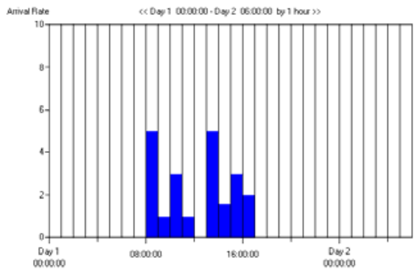


Figure 6 (a). Arrival Schedule for KW 1/2/3

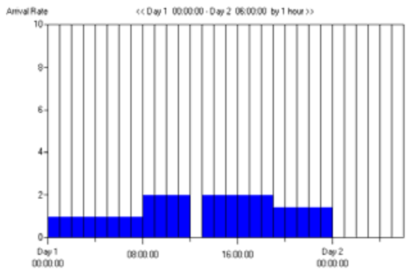


Figure 6 (b). Arrival Schedule for Outside World (KW 4)

Each newly created email carries with itself following information: a) the name of the original sender, b) information about its potential receiver, and c) the information about the current processing stage of the email. The model uses a discrete probability function to determine the percentage of overall newly created emails sent by a knowledge worker to another. For example, in the XHEN network, the probability that KW 1 sends a new email to KW 2 is 0.525, to KW 3 is 0.175 and to somebody in the outside world (i.e. KW 4) is 0.3. These probabilities have been mathematically derived from data collected from a survey.

D1 E1

A B C D2 E2 F G

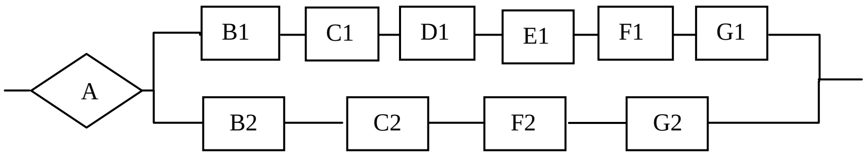
D3 E3

Legends: *A*-Create emails based on a schedule, *B*- Attach current processing phase information to each email, *C*- Probabilistically route emails to other three knowledge workers, *D*- Attach sender-receiver name tag to each email, *E*- Record statistics, *F*- Attach email service time information based on current phase *G*- Hold emails during non-office hours

Figure 7. Email Creation and Initial Routing

All the emails pass through a check point where the receiver's information for each email is inspected. Based on this information, the model routes the email to one of the three branches shown in Figure 8. Each branch handles emails heading out to one of the receivers. The three branches converge at a point from where all the emails enter a decision check point as shown in Figure 7 where the current processing phase of an email is inspected. If the processing phase is "1," i.e. new email, than the email is routed to the top branch where processing begins one by one, but if the processing phase is "2" or "3," emails are routed to the lower branch for their next phase of processing. Emails are then released to knowledge workers depending on the choice of EPS. As soon as emails arrive, knowledge worker is preempted from processing primary tasks. The service time of email comes from a two-dimensional matrix and depends upon their type and the current processing phase.

Once the processing on the email in the part shown in Figure 8 is finished, it is again taken to a branching point for future course of action. If the email in a particular phase has been processed, the information pertaining to its current phase is updated. For example, once the 1st phase of processing on an email is over, the current phase information of the email is updated to 2nd before another knowledge worker begins to work on it. If the email was in 2nd phase, it is updated to 3rd phase. However, only emails of type S and C are able to reach the 3rd phase. Once an email of type F reaches the 2nd stage of processing, model detects that and exits the email out of the system. Before that happens, the email is routed to a part of the model where several email statistics such as time spent by the email in the system, value derived from email, response time, etc. are evaluated.



Legends: *A*-Email phase check, *B1*- Release phase one emails one by one, *C1*- EPS implementation for phase one emails, *D1*- Knowledge worker preempted by phase one, *E1*- Interruption Lag for phase one email, *F1*- Process phase one email, *G1*- Resumption Lag for phase one email. *B2*, *C2*, *F2*, and *G2*, are for phase 2 or 3 emails.

Figure 8. Flows of New and Arriving Emails

5 Limitations and Implications for Future Work

Simulation methodologies have some known drawbacks. Individual differences between subjects cannot be directly accounted due to the absence of real human subjects. On the other hand, it is very difficult to conduct this study using empirical methods such as experiments, field studies, etc. due to lack of control over treatments, subject attrition, change taking place during the experiment, etc.

From a modeling perspective, there are several limitations. First, the model assumes that knowledge workers only exchange emails and not primary tasks. Modeling task dependencies in a project management setting will definitely provide important insights into this problem. Second, we assumed that emails from knowledge workers belonging to the network does not arrive at night. However, with off-shoring gaining prevalence, knowledge workers often find themselves working in different time zones and hence processing emails even at night. Future research should investigate how response times and other performance characteristics are impacted by the choice of email processing strategies in the presence of off-shoring. Third, we modeled only time and frequency based email processing strategies with no other prioritization, forwarding or routing strategies. Future research could focus on comparing the email processing strategies in the presence of various prioritizations and routing schemes. Forth, we assumed that the value of an email changes linearly with time after a certain threshold time has elapsed. It would be interesting to see how communication effectiveness changes when the value of email diminishes non-linearly with time. Finally, this study modeled three knowledge workers and outside world. Future studies could look at larger networks and incorporate some network characteristics.

The approach presented in this study could significantly reduce the problems of email overload, interruptions, addiction, etc. and at the same time, bring more routine and rhythm to the email processing culture within organizations. If workers within a group have a mutual awareness of one another's email processing schedules, the number of daily email interruptions that they must deal with may be reduced. Workers would also have an a priori idea of when they would receive their responses. This information would help them schedule their primary tasks and may lead toward a more productive and disciplined work environment. This proposition could be tested and verified in future research by conducting computer simulation experiments.

6 Conclusion

In the end, we can say that simulation combined with an analytical approach and statistical analysis can serve as a very useful method to conduct studies such as this, that often become unfeasible to pursue due to the time factor and the requirement that researchers continuously monitor subjects for extended periods of time. Through the use of this approach, we tried to address a burgeoning problem of email overload and interruptions that several organizations are facing today. Future research in this direction will certainly help in improving the overall productivity of organizations by helping knowledge workers change their poor email processing practices.

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