ALLOCATING SHARED RESOURCES OPTIMALLY FOR CALL CENTER OPERATIONS AND KNOWLEDGE MANAGEMENT ACTIVITIES

Research-in-Progress

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Abstract

We study a problem where manager of a call center should optimally allocate available resources (man-hours) to call handling and document creation (for knowledge management) tasks. The call center helps service engineers (performing equipment maintenance at client sites) in resolving problems that engineers face during the maintenance activities. Often when an engineer calls, he/she has to wait in a queue when all the call center professionals are busy, leading to wastage of production hours of the engineer. To avoid this situation, call center professionals also create documents addressing problems commonly faced by the engineers and make them available to the engineers through a knowledge management repository. Thus, the problem is to find an optimal allocation of call center resources so that the average waiting time in the queue is minimized. We analyze the model that reveals several important and counter-intuitive insights and provide guidelines for managers of the call center.
Keywords: Knowledge management, Business process modeling, Service management
Introduction

Support and maintenance services continue to be an important source of profit for firms. For instance, Dennis and Kambil (2003) find that the contribution of after-sales services and parts towards revenues across all manufacturing companies is 25%, but are responsible for 40%-50% of their profits. Even during the recent period of economic recession, after sales services was identified to be the key to profits for the firms (Solomon 2009). After sales services was identified to be the key to profits for the firms (Solomon 2009). After sales services was identified to be the key to profits for the firms (Solomon 2009). After sales services was identified to be the key to profits for the firms (Solomon 2009). After sales services was identified to be the key to profits for the firms (Solomon 2009). After sales services was identified to be the key to profits for the firms (Solomon 2009).

Often such services involve maintenance and repair of equipment at the client site, particularly when the equipment are difficult to move from the site, e.g., installed air-conditioning units, machine tools etc. This is done by field technicians who service equipment and attend to maintenance requests at client sites. Rich ethnographic accounts of field maintenance tasks, described generally as technical work, are recognized as being knowledge intensive involving complex troubleshooting and problem solving (Orr 2006). These accounts indicate that individuals performing the task periodically reach the limits of their task knowledge. In such instances, he or she can reach out to other individuals in the community who deal with similar problems of practice (Borgatti and Cross 2003).

While there is a variety of prior research examining the informal mechanisms employed field service personnel to seek help, there has been relatively little work focusing on aspects of formal mechanisms to provide information and help to support knowledge intensive technical work in the field. In spite of the widespread organizational initiatives to establish IT enabled knowledge management systems to support field personnel and end customers, it is only recently (eg. Kumar and Telang 2011) that researchers have begun examining these mechanisms. This paper fills the gap in the literature by providing an analytical model reflecting the complex tradeoffs involved in the creation and management of systems intended to support field service personnel.

Formal field support mechanisms typically have two components (Kumar and Telang 2011). One component is the phone support where engineers take callers calling on a first in first out basis. When a field technician calls while support engineers are busy assisting previous callers, the system managing the phone bank puts callers into a queue till someone is available to take their call. The second component of the formal support is a document repository accessible over the web. The repository for field support typically contains documented solutions for problems frequently faced by the field and engineering documentation helpful for problem solving (Durcikova and Gray 2009).

Prior research suggests that document repositories, to be useful to the users, must be created and maintained by individuals encountering and solving problems on a day to day basis (Durcikova and Gray 2009). The reason is that only then the dynamic non-canonical practices be documented rather than merely general practices that are broadly understood by field personnel and of limited use in addressing exceptional situations that often lead field technicians to seek help. Since the task of engineers in the central support group is to help devise solutions for problems encountered by field technicians, this core group is most knowledgeable about current practices and are thus best placed to author documents for the knowledge repository.

However, this raises a key dilemma faced by central support groups supporting technical field work. The documents require significant resources (man-hours) for creation and maintenance. Therefore, when support engineers (who could potentially answer the calls) are engaged in the task of document creation, then they are unable to provide services to field personnel calling for help. As a result, the wait time of the

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1 As confirmed by the manager of the firm, these documents contain detailed accounts of problems and solutions. As a result, creation of such documents requires large amount of time. Also, new problems constantly arrive (due to product upgrades and new product launches) that demand creation of new documents and updating of old documents.
callers in the queue increases in the current period. Thus, technical support groups confront a trade-off between creating of documents against increased average time spent by callers. The key issue thus is – “What is the optimal allocation of resources (man hours of support engineers) to the task of taking calls and to creating documents for the repository that minimizes the total time spent by a field technician in the phone bank queue?”

Prior research on knowledge repositories (eg. Bock et al. (2005) and Kankanhalli (2005)) discusses personal and organizational factors that influence knowledge sharing and using available information. Lee and Choi (2003) investigate how various factors such as trust, learning, centralization, socialization etc. interact to motivate people to share knowledge. Processes involved in customer service through call centers have been examined in the operations and marketing literature. Atlason et al. (2008) propose an approach for optimally staffing a call center in order to minimize the total costs while maintaining an acceptable level of customer waiting time. Bassamboo and Zeevi (2009) propose an algorithm to staff call centers so that the sum of personnel cost and abandonment penalties are minimized. Park and Zhou (2006) develop a model to find customer life time value based on the quality of services provided by a firm, which includes the service quality of the call center. However, to the best of our knowledge, there is very little research examining the combination of personalized help and online knowledge repositories used in the support of knowledge intensive technical work.

The problem we address is at the crossroads of knowledge management and customer service operations that examines a set of issues relevant for research and for practice. For instance under what conditions is it optimal to allocate more support resources to the creation of documents than to answering incoming calls and vice-versa? What is the optimal decision in allocating resources to document creation and servicing callers when call volumes rises? Such issues are routinely faced in firms which run internal support centers and maintain knowledge management systems for their field technicians. We analyze these issues and derive several interesting and counter-intuitive results that are of immense practical interest. When the call volume increases, the natural reaction would be to increase the rate of call handling. However, our analysis shows that it is more efficient to increase the document creation rate and decrease the call answering rate, so that more field technicians use the document repository. Similarly, when the manager identifies more problems for which documents should be created, the rate of creation of documents should be reduced and call answering rate should be increased.

**System Description and Notations**

The current support center system consists of a call center where a field technician calls to resolve his issue with the help of support engineers, and an alternative knowledge management system where the field technician can visit and search relevant documents to obtain solution to his problem. When a field technician calls the call center and the center is not free to attend his call, he joins a queue; otherwise, a support engineer helps him in resolving his problem. We assume that field technicians call the call center according to a Poisson process with a rate $\lambda'$. The support center resolves the problems according to an exponential process with rate $\mu'$.

The documents in the knowledge management system are created by the support engineers – a support engineer either handles calls or creates documents at a time. The task of either handling calls or creating documents is assigned to a support engineer by the manager of the support center. For creating documents, the manager selects common problems faced by the field technicians (for which field technicians make calls or visit the knowledge management system). Suppose the manager identifies, on an average, $p$ fraction of all problems arriving at the support center for which documents should be created. We assume that these problems are identified according to a Poisson process with rate $\lambda_d$. We assume that the documents are published at the knowledge repository at a rate $\mu_d$ according to an exponential process. The field technicians are assumed to be arriving according to a Poisson process with mean rate $\lambda''$ to the knowledge repository and resolve their problems according to an exponential process with rate $\mu''$.

At a higher level, the whole support system can be conceptualized as a server where field technicians arrive according to a Poisson process with rate $\lambda$ and their problems are resolved according to an exponential process with rate $\mu$. It is also the rate at which field technicians would have been served by the support engineers if there was no knowledge management repository. This support system serves as the
benchmark (basic) system because the resources of this basic system are divided into two services – service through calls and creating documents. Table 1 shows the notations that will be used in modeling the system and Figure 1 illustrates the benchmark system and the support center.

In this study, we analyze the systems (the call center, document creation system and the benchmark) at their steady states. Therefore, \( \lambda < \mu, \lambda' < \mu' \) and \( \lambda_D < \mu_D \).

<table>
<thead>
<tr>
<th>Notation</th>
<th>Explanation</th>
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<tr>
<td>( \lambda )</td>
<td>Poisson arrival rate of the field technicians with problems to the support center</td>
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<tr>
<td>( \mu )</td>
<td>Exponential service rate of the benchmark system</td>
</tr>
<tr>
<td>( \lambda' )</td>
<td>Poisson arrival rate of the field technicians (callers) at the call center</td>
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<tr>
<td>( \lambda'' )</td>
<td>Poisson arrival rate at the knowledge management system</td>
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<td>( \mu' )</td>
<td>Exponential service rate of the call center</td>
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<tr>
<td>( \mu'' )</td>
<td>Exponential service rate at the knowledge management system</td>
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<tr>
<td>( \mu_D )</td>
<td>Exponential rate at which the support engineers publish documents at the knowledge management system</td>
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<tr>
<td>( \lambda_D )</td>
<td>Poisson rate at which new problems are identified by the manager for creating documents</td>
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<tr>
<td>( p )</td>
<td>Fraction of problems that are selected by the manager for document creation</td>
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**Model: Objective Function and Constraints**

The manager of the support center wants to determine the optimal service rate through call (\( \mu' \)) and allocate tasks to a support engineer based on \( \mu' \) in such a way that the time spent (\( TT = \frac{1}{\mu - \lambda} \)) by a field
technician in the call center is minimized. Therefore, the objective function is stated as
\[
\arg \min_{\mu'} \left( \frac{1}{\mu' - \lambda} \right)
\]
(1)

Notice that the objective function is differentiable at all $\mu'$ since $\mu' - \lambda > 0$. Decrease in $\mu'$ tends to increase $TT$ (from Equation (1)); however, it facilitates increased $\mu_0$ which tends to decrease $\lambda'$ (by increasing $\lambda''$) and therefore decrease $TT$. Thus, this optimization problem balances the tradeoff between reduced rate of service through calls against increased rate of document creation. The manager assigns $\mu'/\mu$ fraction of support engineers the task of service through calls and rests are assigned the task of document creation.

It is apparent from Figure 1 and the preceding discussion that the arrival rate of field technicians at the benchmark system ($\lambda$) is split between the call center and the knowledge management. Both the arrivals – at the call center and the knowledge management system – are according to the Poison processes. Thus, the first constraint, arrival rate constraint, is
\[
\lambda = \lambda' + \lambda''
\]
(2)

The arrival rate of service engineers at the knowledge management system ($\lambda''$) depends on how frequently new and relevant documents are published in the repository ($1/\mu$). $\lambda''$ is expected to increase when $1/\mu$ decreases. For mathematical tractability, the relationship between $\lambda''$ and $\mu$, referred to as the knowledge management system arrival constraint, is represented as
\[
\lambda'' = A + B \mu
\]
(3)

where $A>0$ and $B<0$. $A$ (maximum achievable arrival rate) represents the arrival rate at which field technicians visit the knowledge management system when the number of documents created per unit time is large. $B$ denotes the sensitivity of the field technicians towards the freshness of documents in the repository. A higher magnitude of $B$ indicates that the field technicians are more sensitive to the rate of refreshment of the documents.

The rate at which the manager identifies problems for creating documents is
\[
\lambda_D = p \lambda.
\]
(4)

As mentioned earlier, the support system is like a server where a support engineer resolves problems of field technicians by providing service through call or creating documents. At any instant, $\frac{\lambda}{\mu}$ problems (of field technicians who call and who search at the knowledge management system) are processed in the support center. Average time taken for resolving a problem is $\frac{1}{\mu}$; therefore, $\frac{\lambda}{\mu}$ amount of time is required to resolve the problems under processing at any instant of time. As the resources are split between two tasks of service through calls and document creation, the constraint on resources (service engineers’ time), referred to as the resource constraint, is
\[
\frac{\lambda}{\mu^2} = \frac{\lambda'}{\mu^2} + \frac{\lambda_D}{\mu^2}.
\]
(5)

Note that the stochastic systems in this setup are the call center and document creation task that are assumed to be in steady states. The constraint Equations (2) and (3) demonstrate the endogenous relationships between the arrival rates at the call center and document repository. Equation (4) provides the relationship between the arrival rates at the call center, document creation rate and exogenous parameter $\lambda$. Equation (5) balances the resources required by the two systems (in steady states) and the resources available at the overall support center (based on $\lambda$ and $\mu$). The manager has sufficient man-hours available as per the requirement of the whole system – the problem is of optimally allocating the available man-hours among the two systems.
Solution of the Model

In the model, we have following exogenous parameters: \( \lambda, \mu, A, B \) and \( p \). By simultaneously solving Equations (2), (3), (4) and (5), we obtain the solution for \( \lambda' \), which is substituted in Equation (1). First order and second order derivatives of the objective function in Equation (1) are derived to find the conditions for \( \mu' \) that minimizes \( TT \); the conditions are presented in Lemma 1 shown below.

**Lemma 1:** The value of optimal \( \mu' \) can be obtained by solving the following Equation\(^2\)

\[
2B^2\mu'\lambda\mu^2 - (B^2 - 2B\mu'p(A + \mu' - \lambda))\lambda + \mu'^4p^2\lambda^2\mu^4 = 0.
\]

subject to

\[
B\mu'\lambda + (-B + \mu'p(A + \mu' - \lambda))\mu^2 \neq 0 \quad \text{and} \quad \frac{(-6B^2\lambda^2 + 2B\mu'\lambda(3B + \mu'p(-6\lambda + 7\mu' + 6\lambda)))\mu^4 - 2(B^3 - 3B^2\mu'p(A + \mu' - \lambda))\lambda}{\mu'^3((B\mu'\lambda + (-B + \mu'p(A + \mu' - \lambda))\mu^2)^3}) > 0
\]

We observe through numerical experiments that Equation (6) has two real roots and one of these is a global minima that minimizes \( TT \). The optimal \( \mu' \) is used to determine \( \lambda' \). Equation (4) provides the value of \( \lambda_D \). The value of \( \lambda' \) is substituted in Equation (2) to find the value of \( \lambda'' \); \( \lambda'' \) is then substituted into Equation (3) to compute \( \mu_D \). Usually, the support center has multiple support engineers. Therefore, the manager should assign \( \frac{\mu'}{\mu} \) fraction of support engineers to service through call and rest to document creation. To illustrate the calculations of \( TT \) minimizing \( \mu' \) along with other endogenous parameters of the support center, we assume that \( A = 6,000, B = -2,011,198,931, \lambda = 12,000, \mu = 15,000 \) and \( p = 0.00028 \). The rates of arrivals and services are weekly. By substituting these values in Equation (6) and using Equation (7), we find that \( \mu' = 13,723.89 \) minimizes the cost \( TT \) in Equation (1). Other parameters can be computed as: \( \lambda' = 9062.76, \lambda'' = 2,937.2, \lambda_D = 3.42, \mu_D = 810.34 \) and \( TT \) is 2.16 minutes.

Analysis of the Model

In this section, we determine the sensitivities of the decision variables in the model towards the changes in the exogenous variables by performing comparative statics and numerical experiments on the model.

**When the Arrival Rate at the Support Center Increases**

We differentiate Equation (6) with respect to \( \lambda \) (\( \mu' \) is differentiated implicitly with respect to \( \lambda \)) to determine the first order derivative \( \frac{d\mu'}{d\lambda} \). To determine how \( \mu' \) changes with increase in \( \lambda \), \( \frac{d\mu'}{d\lambda} \) is evaluated at given values of parameters \( \lambda, \mu, A, B, p \) and corresponding \( \mu' \). We perform numerical experiments to find the changes in \( \mu' \) with changes in \( \lambda \). We find that when \( \lambda \) increases, the optimal decision for the manager of the support center is to reduce the service rate at the call center (\( \mu' \)) and increase the rate of document creation (\( \mu_D \)). Eventually, \( \lambda' \) decreases.

When \( \lambda \) increases, suppose by \( \Delta \), and the manager decides not to change \( \mu' \) and increase only \( \mu_D \), the increase in arrival rate at the document repository is less than \( \Delta \). Thus, arrival rate at the call center increases which increases \( TT \) (since \( \mu' \) is constant). Similarly, \( TT \) also increases when the manager decides not to change \( \mu_D \) and increases \( \mu' \). Interestingly, \( TT \) decreases when both \( \mu' \) and \( \mu_D \) are changed. The optimal \( \mu_D \) is such that the increase in \( \lambda'' \) is more than \( \Delta \), so that \( \lambda' \) decreases. In order to achieve higher \( \mu_D \), increased (respectively, reduced) resources (time of a support engineer) should be assigned to document creation (respectively, service through calls). Although \( \mu' \) decreases, it is high enough so that the expected number of field technicians in the call center system reduces.

\(^2\) We assume that exogenous parameters attain values such that \( \lambda < \mu, \lambda' < \mu' \) and \( \lambda_D < \mu_D \), because from queuing theory we know that these conditions are required by queuing systems to achieve steady states.

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As mentioned earlier, usually there are multiple engineers at the support center. When $\lambda$ increases, few support engineers should be shifted from the task of service through calls to document creation. We find that decrease in the $\mu'$ is more than increase in $\mu_D$ with increase in arrival rate. Therefore, support engineers who can efficiently create new documents should be shifted from the task of service through calls to document creation task.

**When the Fraction of Problems Selected for Documentation Increases**

We differentiate Equation (6) with respect to $p$ to determine $\frac{d\mu'}{dp}$ and perform numerical analysis which shows that the optimal $\mu'$ increases and $\mu_D$ decreases with increase in $p$. Increase in $p$ increases $\lambda_D$ (Equation 5). As a result, $\frac{\lambda_D}{\mu_D}$ in the resource constraint (Equation 6) increases. Suppose the manager increases only $\mu_D$ and does not change $\mu'$. Then, $\lambda''$ increases and $\lambda'$ decreases which leads to decreased $TT$ in Equation (1) because $(\mu' - \lambda')$ increases. However, by increasing $\mu'$ and decreasing $\mu_D$, $TT$ can be further reduced. A small reduction in $\mu_D$ causes large reduction in $\lambda''$ due to decreasing rate of returns of $\mu_D$ in Equation (4), leading to large increase in $\lambda'$. As a result, $\frac{\lambda_D}{\mu_D}$ and $\frac{\lambda'}{\mu'}$ (where $\mu'$ is the previous rate of service) increase. Since $\mu'$ has decreasing rate of returns in the resource constraint, a significant increase in $\mu'$ is required, which is more than increase in $\lambda'$. The difference between $\mu'$ and $\lambda'$ when $\mu'$ is changed is higher than the difference between these two when $\mu'$ is not changed. Therefore, $TT$ when $\mu'$ is changed is smaller than when $\mu'$ is not changed.

Intuitively, though $TT$ can be decreased by increasing $p$ as that increase $\mu_D$ and $\lambda''$ and consequently reduces $\lambda'$. However, by reducing $\mu_D$, manager can release resources for increasing $\mu'$ which decreases $TT$ more than if $\mu'$ is not changed, even though $\lambda'$ increases due to decrease in $\mu_D$. We find that when $p$ increases, increase in the rate of service through calls is higher than decrease in the rate of document creation. Therefore, the support center manager should shift those support engineers from the document creation task to service through calls that are efficient in solving problems on call.

**When Maximum Achievable Arrival Rate at Knowledge Management System Increases**

We differentiate Equation (6) with respect to $A$ to determine $\frac{d\mu'}{dA}$. Numerical analysis reveals that when $A$ increases, optimal $\mu'$ increases and optimal $\mu_D$ decreases. When $A$ increases and $\mu'$ is not changed, manager reduces $\mu_D$ by a very small amount relative to its original value. Despite this decrease in $\mu_D$, $\lambda''$ increases due to the increase in $A$. As a result, $\lambda'$ decreases. Consequently, $(\mu' - \lambda')$ increases and $TT$ decreases. Decreased $TT$ with reduced $\mu_D$ and constant $\mu'$ is expected because increased $A$ implies more field technicians preferring visiting the knowledge management system which reduces the arrival at the call center.

When the manager changes both $\mu'$ and $\mu_D$, we find that $\mu_D$ should be decreased to an extent that $\lambda''$ increases and $\lambda'$ increases. Decrease in $\mu_D$ results into increase of $\frac{\lambda_D}{\mu_D}$ and increase in $\lambda'$ leads to increase in $\frac{\lambda'}{\mu'}$ (where $\mu'$ is same as before $A$ changes). Since $\mu'$ has decreasing rate of return in the resource constraint, a significant increase in $\mu'$ is required. The increase in $\mu'$ is larger than the increase in $\lambda'$, and therefore $TT$ decreases.

Intuitively, the reason for increasing optimal $\mu'$ with increase in $A$ is similar to that explained in Section 4.2 for increase in $\mu'$ with increase in $p$. Of course, increase in $A$ would reduce arrival rate at the call center and therefore reduce the total time spent by a field technician at the call center. However, reducing the rate of document creation enables the manager to release resources for service through calls, increase in which can reduce $TT$ more than when the rate of service through call remains constant, despite increase in $\lambda'$. We find that increment in $\mu'$ is more than decrease in $\mu_D$. Therefore, support engineers who are efficient in providing service through calls should be shifted from the document creation task since the increase in the rate of service through calls is high.
When Sensitivity towards Relevance of Documents Increases

We differentiate Equation (6) with respect to $B$ to find $\frac{d\mu'}{d\mu}$. Numerical analysis shows that when $B$ increases, optimal $\mu'$ increases and optimal $\mu_D$ decreases. When $B$ increases, field technicians value the documents in the knowledge management system more than before resulting into increase in $\lambda''$ and decrease in $\lambda'$. Therefore, the manager can reduce the rate of creating documents while maintaining an increased rate of arrival at the knowledge management system than before (when $B$ increases). Decrease in $\mu_D$ increases $\frac{\lambda}{\mu'}$, which compensates for decrease in $\frac{\lambda}{\mu'^2}$ due to decrease in $\lambda'$. Thus, $TT$ decreases.

However, $TT$ can be minimized by increasing $\mu'$ and significantly decreasing $\mu_D$. A large decrease in $\mu_D$ leads to decrease in $\lambda''$ (Equation (4)) and increase in $\lambda'$. Also, $\frac{\lambda}{\mu_D}$ increases significantly. Increase in $\mu'$ compensates for increase in $\frac{\lambda}{\mu_D}$ and $\lambda'$. By significantly decreasing $\mu_D$, the manager can shift considerable resources to the service through call center to achieve significant increase in $\mu'$ which leads to reduced $TT$ despite increased $\lambda'$, which does not increase significantly due to increased $B$.

We find that increase in optimal $\mu'$ is not always more than decrease in $\mu_D$. In the beginning when $B$ is small, e.g., when $A = 5,800$, $p = 0.00028$, $\lambda = 12,100$ and $\mu = 15,000$, $B = -2.111 \times 10^6$, $\mu_D$ is high. Thus, a large decrease in $\mu_D$ is required to have a significant reduction in $\lambda''$ due to diminishing rate of return of $\mu_D$ in Equation (4). Consequently, increase in $\mu'$ is less than decrease in $\mu_D$. When $B \geq -2.061 \times 10^6$, the value of $\mu_D$ is small. Therefore, a small decrease in $\mu_D$ decreases $\lambda''$ significantly. Thus, a large increase in $\mu'$ is required to compensate for increases in $\frac{\lambda}{\mu_D}$ and $\frac{\lambda}{\mu'^2}$, the increase in $\mu'$ is larger than decrease in $\mu_D$.

Conclusion and Future Research

In this research, we consider a support center of a firm that provides solutions to the problems of field technicians by two means – a call center and a knowledge management system. Engineers at the support center are responsible for providing service through calls and maintaining the knowledge repository. We address the problem faced by the manager of allocating the shared resources (man hours of the support engineers) between the tasks of providing service through calls and creating documents for the knowledge management system such that the time spent by a field technician in the call center is minimized.

We derive conditions that provide the optimal rates at which service through calls should be provided and documents should be created. Based on these rates, the man hours are distributed between the two tasks. We also study the changes in these optimal rates when one of the exogenous parameter of the system changes; this analysis enables us to draw several interesting insights. We find that although increased document creation rate can increase the number of field technicians visiting the knowledge management system, under several conditions, it is optimal for the manager to decrease the document creation rate and increase the rate of service through calls.

We also have data regarding the arrivals of field technicians to the call center and the knowledge management system, and the service times at the call center. In the future, we plan to use this data for estimating the parameters and validate the assumptions (such as the distributions assumed for arrivals of field technicians and services at the call center) used in the model. We also plan to design simulation experiments to further explore the impact of changes in the exogenous parameters on the optimal decisions of the manager of the call center.

References

