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Operational impact on the environment: Managing service systems with environmental deterioration

Ye Shi^a, Yugang Yu^{a,*}, Lizhi Wang^b^a School of Management, University of Science and Technology of China, Hefei 230026, PR China^b Industrial and Manufacturing Systems Engineering, Iowa State University, Ames, Iowa 50011, United States

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ABSTRACT

We consider a dynamic environmental and marketing decision problem for natural service systems with environmental deterioration. Demand of the service is attracted by both the environmental quality and the marketing efforts, but customers also generate wastes that greatly degrade the environment. As a result, the manager of the service system may decide to make a cleaning up effort to help the environment recover in addition to its self-healing capability. The manager's objective is to maximize the net present value of the total profit over a planning horizon by determining both the environmental and marketing efforts in each period.

To show how the environment affects the operation, we characterize the monotonicity of optimal decisions w.r.t. the environmental quality. To investigate operational impact on the environment, we present a complete characterization of the steady-state environmental quality, and prove the global convergence of the environmental quality in the long run. The convergence result implies that the environment may gradually degrade over time. A case study is presented to show what can be done to control the degradation. An interesting finding is that the steady-state environmental quality may improve even if the average amount of wastes produced per customer increases.

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1. Introduction

In modern service industry, managers learn to coordinate the conflict between profit making and environment protection. For tourism industry, the coordination is extremely important since tourists are particularly sensitive to environmental conditions. The process of serving tourists consumes natural resources and generates wastes, thereby resulting in environmental deterioration. For example, cruise ships in the Caribbean are estimated to produce more than 70,000 tons of wastes each year. These wastes can degrade the physical appearance of the water and shoreline.¹ Hassan (2000) highlights that the negative effects of environmental deterioration on a destination can weaken its long-term comparative advantage and reduce tourist demand.

To develop tourism in a sustainable manner, environment protection has been integrated into operation of tourism industry. Moreover, the classical operation, for example, marketing has been updated by incorporating the awareness of environment protection, which contributes to controlling of tourist visits and easing the

environmental burden of serving tourists. Such marketing has been shown to be an efficient and effective method in sustainable tourism management (Dorji, 2001).

The purpose of this paper is to study a dynamic service model with environmental deterioration to better understand operational impacts on the environment. By studying such a model we aim to provide insights into the following questions: (i) How do the environmental quality and other system conditions affect optimal decisions? (ii) Will the environmental quality converge to a steady state in the long run? (iii) If a steady-state environmental quality exists, how do system conditions affect this quality?

A concrete example of our model is Jiuzhaigou, which is a scenic spot in China. The Jiuzhaigou is famous for excellent landscape, including multi-level waterfalls, colorful lakes, and snow-capped peaks. Such a great landscape attracts a large number of tourists to visit. During the high tourist season (from June to October), the number of tourists averages up to 12,000 per day, resulting in 1560 tons of waste water, among other solid wastes (Zhang and Zhu, 2007). Moreover, Chinese government agents provide daily report on the environmental conditions of these popular destinations.² To maintain the environmental quality of Jiuzhaigou, an important job

* Corresponding author. Tel.: +86 5513606187; fax: +86 5513600025.

E-mail addresses: hecules@mail.ustc.edu.cn (Y. Shi), ygyu@ustc.edu.cn (Y. Yu), lzwang@iastate.edu (L. Wang).

¹ Readers are referred to <http://www.unep.org/resourceefficiency/Business/SectoralActivities/Tourism/> for other examples on environmental deterioration caused by tourism.

² The information on water quality of scenic spots in China refers to <http://www.yangshitianqi.com/jiuzhaigou/kongqizhiliang.html>.

for the managers is to clean up the wastes generated by tourists, even if the local ecosystem can heal itself.

Motivated by the story of Jiuzhaigou Valley, we consider a dynamic service system in which the demand of the service products (i.e., the number of customer visits) is an increasing function of the environmental quality and marketing efforts. The increasing property of the demand function w.r.t. the environmental quality characterizes tourist demand for better environmental conditions, for example, fresher air and cleaner water (Mihalic, 2000; Li, 2004). The environment suffers deterioration during the process of serving customers. Motivated by the example of Jiuzhaigou, we use *the wastes that customers generate* to represent such deterioration. Generally speaking, more wastes are generated as more customers arrive. Therefore, the deterioration is an increasing function of the demand. Although the environment can heal itself, the system manager needs to make efforts to help the environment. The objective is to maximize the discounted profit by periodically determining optimal marketing and environmental efforts. We analyze optimal marketing and environmental efforts, and then characterize the environmental quality in the long run. These analytical results illustrate the operational impact on the environment. Our model covers the tradeoffs between coordinating environment protection and marketing operation. In particular, the manager can enhance marketing efforts to increase current profit at the expense of future environmental quality. To make up for environmental deterioration, the manager can invest in environmental efforts, which in turn reduces the current profit. By studying such a service system, we make several contributions as follows.

First, we characterize monotonicity of optimal marketing and environmental decisions, that is, optimal environmental efforts decrease as the environmental quality improves, and optimal marketing efforts increase with the average amount of wastes produced per customer. However, optimal marketing efforts do not necessarily increase with the environmental quality, which depends on the structure of the demand function.

Second, we study the system in the long run, and characterize the steady-state environmental quality. From a technical perspective, this part of work is an extension of the work of Popescu and Wu (2007). In particular, the decision in Popescu and Wu (2007) is single-dimensional price and steady-state decision is assumed to be in the interior of the feasible region. In contrast, the decisions in our problem are two-fold (marketing and environmental decisions), both of which can be interior or on the boundary of the feasible region. This difference causes technical difficulty in characterizing the steady-state decisions. We extend the variational approach used by Popescu and Wu (2007) to characterize the steady state of our problem. An interesting steady state where both marketing and environmental efforts are zero is called as the baseline situation. In such situation, the system admits the steady state by balancing deterioration and self-healing without any human efforts. The baseline situation is used as a benchmark to show whether the environment improves after marketing and environmental activities are implemented.

After characterizing the steady state, we show the global convergence of the system states. The convergence result implies that if the initial environmental quality level is higher than the steady-state level, then the manager will enhance marketing efforts and reduce environmental efforts to make more profit. As a result, the environmental quality will continue decreasing to the steady-state level, which is essentially a skimming strategy. When starting with a lower initial environmental quality than the steady-state level, the manager will reduce marketing efforts and enhance environmental efforts. Then, the environmental quality will continue increasing to the steady-state level, which is similar to a penetration strategy. When the initial environmental quality is equal to

the steady-state one, both the marketing and environmental decisions remain constant (Popescu and Wu, 2007). In particular, the skimming strategy implies that the environmental quality gradually degrades over time (see Fig. 5), and this kind of development hurts the environment of the destination. This development is *not* healthy for the destination. A case study is presented to show what can be done to control the unhealthy development.

The remainder of this paper is organized as follows. Section 2 reviews relevant literature. Section 3 provides a formulation of the model. Section 4 shows how environmental quality and other system parameters affect optimal decisions. Based on the results gained in Section 4, we next focus on characterizing the steady-state environmental quality in Section 5. The steady-state analysis illustrates operational impact on the environment in the long run. In Section 6, a case study is conducted to analyze the sensitivity of the steady-state environmental quality and what can be done to control unhealthy development from the social perspective. Section 7 presents two extensions of the original model by considering (i) customer uncertain estimation on the environmental quality and (ii) bi-objective decision making. Section 8 presents the concluding remarks and some potential extensions.

2. Literature review

In general, our work is related to two streams of research. The first stream is on environmental sustainability and marketing in the tourism field. Cohen (1978) is one of the pioneering papers addressing the negative effects of developing tourism on the environmental conditions. After that, a large body of literature emphasizes the importance of incorporating sustainability into tourism development (e.g., Butler, 1991; Mieczkowski et al., 1995), and proposes ideas or methods for managing tourism developed with sustainability (e.g., Gössling et al., 2002; Waligo et al., 2013; Zhang et al., 2015a). In particular, there is a growing interest in protecting the environment of tourism sites through operational activities, such as, tourism marketing (Middleton and Hawkins, 1998; Jamroz, 2007). However, most of these studies are empirical or case studies, and few of them concentrates on the marketing and environmental decisions from a quantitative perspective. Our work is probably the first attempt to provide both qualitative and quantitative insights into the connection between marketing and environmental decisions. In particular, we contribute to the first stream by quantitatively characterizing steady-state environmental quality and optimal decisions.

The second stream is the literature on the management of deteriorating or obsolete product/capacity in the OR/MS field, such as Nahmias (1975); Bakker et al. (2012) and Xiuli Chao and Chen (2009). In these previous studies, product/capacity is assumed to be deteriorating over periods, in a manner similar to environmental deterioration. However, several characteristics of natural service systems differentiate them from production systems. (i) The demand in natural service systems is directly affected by environmental quality. (ii) Service consumption will result in environmental deterioration. (iii) Some natural systems (e.g., mountains and forests) are growing and self-healing after deterioration (Blanco, 2012). To the best of our knowledge, these characteristics are not captured by most current models for production systems, and few papers provide insights into marketing operation in natural systems with environmental deterioration. Compared with these papers, our work contributes to incorporating the three characteristics into an OM problem, and analyzing how these characteristics affect the marketing and environmental operation.

In addition, our work is also related to the growing body of literature on customer environmental awareness in OM problems. For

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