© 2019 IJSRSET | Volume 6 | Issue 3 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section : Engineering and Technology
DOI : https://doi.org/10.32628/IJSRSET1962158

Optimization of Cybercafe Internet Service and Costs under Stochastic Demand

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ABSTRACT

We consider a set of cybercafes faced with an optimal choice of bandwidth for internet service under stochastic stationary demand. The choice is made over uniformly time horizons with a goal of optimizing costs. Considering customer demand and operating costs of internet service at cybercafes, we formulate a finite state markov decision process model where states of a markov chain represent possible states of demand for internet service. An operational cost matrix is generated; representing the long run measure of performance for the markov decision process problem. The problem is to determine an optimal bandwidth adjustment policy at cybercafes so that the long run operational costs are minimized for the given state of demand. Using dynamic programming, the optimal bandwidth adjustment policies are determined at least cost over a finite period planning horizon. Results from the case study demonstrate the existence of an optimal state-dependent option for bandwidth adjustment policy and costs of internet service at cybercafes.

Keywords : Bandwidth Adjustment; Cost Optimization; Internet Service; Stochastic Demand

I. INTRODUCTION

Communities all over the world use the internet to access information for academic, business and social welfare. The internet therefore becomes a vital tool in bridging gap between the ICT disadvantaged people; according to Doezi [1]. The e-business era today has changed the mode of business operations and communication among millions of people all over the world. The internet is a vital means for job seekers; acting as a platform where employers and employees interact for possible recruitment. In the health sector, the internet allows healthy living to access medication and drugs using the e-pharmacy platform. Citizens from several countries have benefited in education; since quality degrees can be earned from reputable institutions of leaning without one leaving his/her town or village [2]. The use of internet in Uganda is picking at a steadily increasing rate; Uganda being one of the first countries in sub-Saharan Africa to gain full internet connectivity [3]. Although a substantial number of cybercafes are scattered in urban areas, major initiatives require bringing internet services to rural areas as well. Stewart J [4] defines a cyber cafe as a cafe or shop open to the public; where a computer can be hired for specified periods to access the internet, write a CV or play a game. In African countries, power outages pose a major problem against information/service provision as noted by Jensen [5].Nyomoko,Richard and Makori[6] vividly point out how internet service as a venture for business investment has essential areas to evaluate with respect to the cybercafe to invest in, how decisions made improve cybercafe business performance and the performance of cybercafe after implementation. However, Farbey [7] shows how the use of such areas evaluated provide varying responses to different organizations. Situations vary from organization to organization and the range of circumstance the technique would be applicable is extremely wide. As a business investment venture, Berghout [8] concludes that both qualitative and quantitative methods are desirable in evaluation cybercafe investment strategies among potential users.

II. OBJECTIVES OF THE STUDY

2.1 General Objective

The general objective of the study was to develop a mathematical model that optimizes bandwidth adjustment decisions and costs of internet service in cybercafes under stochastic demand in Uganda.

2.2 Specific Objectives

Specifically, the study sought to attain the following objectives:

- To select and define model variables and parameters
- To determine demand transition and operational cost(reward) matrices of internet service in cybercafes
- To develop a finite-period dynamic programming model that optimize bandwidth adjustment decisions and costs in cybercafes
- To solve the model using a real life case study

III. LITERATURE REVIEW

According to Clark [9] cost allocation and pricing of internet is vital to give the relationship between the range of service offered to users and the cost of providing these services. The author provides a new scheme for resource allocation, pricing and the expected capacity allocation. This is compared with a number of resource allocation schemes under consideration. The literature behind internet resource pricing models, mechanisms and methods benefits from the works of Huan H,Xu K and Li Y[10] ; who guide us to understand how to effectively use internet resources by examining pricing strategies, mechanisms and methods. Therefore, with the evolution of service types, several corresponding mechanisms which can ensure price implementation and resource allocation with special reference to utility optimization economics. As a mode of improving internet service provision, Turan, Nihatkasap and Hű̃seyin [11] provide a heuristic algorithm from firm's perspective at managerial level to solve the bandwidth sourcing and task allocation problem. The authors illustrate how bandwidth provides selection and task allocation with stochastic constraints; where delay and jitter are considered as random variables in order to capture the stochastic nature of telecom network environment. Serafeimidis and Smithson [12] however argue the difficulty task associated with measuring and identifying the potential benefits and costs of an IT investment. It is also true that IT evaluation is complex and elusive Dillon [13]; since a substantial amount of money is lost because of inability of organizations to realize benefits.

While studies have tried to examine the dynamics of price and cost in internet service provision, a stochastic approach is sought to handle demand uncertainty among users in cybercafes with special reference to bandwidth provision as a cost minimization strategy.

IV. MODEL DESCRIPTION

4.1 Notation

Sets

Z Set of bandwidth adjustment policies

i,j Set of states of demand policies

b Set of cybercafes

Parameters
Demand
D Demand matrix
Q Demand transition matrix

Costs
C Operational cost matrix
c_0 Unit operational cost
e Expected costs
a Accumulated costs

Probabilities
Q^{K}_{ij} Probability that demand changes from state i to state j given adjustment policy Z

Others
F Favorable demand
U Unfavorable demand
n,N Stages
M Customer matrix
$i\varepsilon\{F,U\}$, $Z\varepsilon\{0,1\}$, $b=\{1,2\}$

We consider a set of cybercafes that periodically adjust bandwidth to meet customer requirements at least cost. The demand for internet service during each time period over a fixed planning horizon is described as either favorable (denoted by state F) or unfavorable (denoted by state U) and the demand of any such period is assumed to depend on the demand of the preceding period. The transition probabilities at cybercafes over the planning horizon from one demand state to another may be described by means of a Markov chain. Suppose one is interested in determining an optimal course of action namely; to adjust bandwidth for faster internet speed (a decision denoted by Z=1) or not to adjust bandwidth (a decision denoted by Z=0) during each time period over a fixed planning horizon where Z is a binary decision variable. Optimality is defined such that the minimum operational costs at cybercafes are accumulated at the end of N consecutive time periods spanning the planning horizon. In this paper, a two-period (N=2) planning period is considered for two (b=2) cybercafes.

4.2 Finite-Period Dynamic Programming Model

Recalling that the demand can either be in state F or in state U, the problem of finding an optimal bandwidth adjustment policy can be expressed as a finite period dynamic programming model. Assuming $h_n(i)$ denotes the optimal expected costs accumulated at the end of periods n,n+1,…………N given that the state of the system at the beginning of period n is $i\varepsilon\{F,U\}$.The recursive equation relating h_n and h_{n+1} is

$$h_n(i) = min_Z[Q^Z_{iF}(b)C^Z_{iF}(b) + h_{n+1}(b,F), Q^Z_{iU}(b)C^Z_{iU}(b) + h_{n+1}(b,U)]$$

$i\varepsilon\{F,U\}$, $Z\varepsilon\{0,1\}$, $b=\{1,2\}$ $n=1,2,\ldots\ldots N$
together with the conditions

$$h_{N+1}(b,F) = h_{N+1}(b,U) = 0$$

This recursive relationship may be justified by noting that the cumulative operational costs $C^Z_{ij}(b) + h_{N+1}(b,j)$ at cybercafe b resulting from state $j\varepsilon\{F,U\}$ at the beginning of period n+1 from state $i\ \varepsilon\{F,U\}$ at the beginning of period n occurs with probability $Q^K_{ij}(b)$
Clearly

$$e^Z(b) = [Q^Z(b)][C^Z(b)]^T \quad (2)$$

$Z\varepsilon\{0,1\}$, $b=\{1,2\}$

where "T" denotes matrix transposition. Hence, the dynamic programming recursive equations

$$h_N(i,b) = min_Z[e^Z_i(b) + Q^Z_{iF}(b)h_{N+1}(b,F) + Q^Z_{iU}(b)h_{N+1}(b,U)] \quad (3)$$

$$h_N(i,b) = min_Z[e^Z_i(b)] \quad (4)$$

result where (4) represents the markov chain stable state.

4.1 Computing $Q^Z(b)$ and $C^Z(b)$

The demand transition probability from state i ε{F,U} to state j ε{F,U} at cybercafe b , given adjustment policy Z may be taken as the number of customers observed with demand is initially in state i and later with demand changing to state j divided by the number of customers over all states.

That is

$$Q_{ij}^{Z}(b) = M_{ij}^{Z}(b)/[M_{iF}^{Z}(b) + M_{iU}^{Z}(b)]$$

iε{F,U}, b={1,2} , Zε{0,1} (5)

The operational costs can be expressed as the product of unit operational costs and demand for internet sevice

That is

$$C_{ij}^{Z}(b) = c_0(b) D_{ij}^{Z}(b) \quad (6)$$

4.2 Optimization during Period 1

When demand is favourable (ie in state F),
the optimal bandwidth adjustment policy during period 1 is

$$Z = \begin{cases} 1 & if \quad e_F^1(b) < e_F^0(b) \\ 0 & if \quad e_F^1(b) \geq e_F^0(b) \end{cases}$$

The associated operational costs are then

$$h_1(b,F) = \begin{cases} e_F^1(b) & if \quad Z = 1 \\ e_F^0(b) & if \quad Z = 0 \end{cases}$$

Similarly, when demand is unfavourable (ie. in state U), the optimal bandwidth adjustment policy during period 1 is

$$Z = \begin{cases} 1 & if \quad e_U^1(b) < e_U^0(b) \\ 0 & if \quad e_U^1(b) \geq e_U^0(b) \end{cases}$$

The associated operational costs are

$$h_1(b,U) = \begin{cases} e_U^1(b) & if \quad Z = 1 \\ e_U^0(b) & if \quad Z = 0 \end{cases}$$

4.3 Optimization during period 2

Using (3) and (4), and recalling that a^{Z}_{i} (b) denotes the already accumulated operational costs at the end of period 1, as result of decisions made during that period, it follow that

$$a_i^Z(b) = e_i^Z(b) + Q_{iF}^Z(b) min[e_F^1(b), e_F^0(b)] + Q_{iU}^Z(b) min[e_U^1(b), e_U^0(b)]$$

$$a_i^Z(b) = e_i^Z(b) + Q_{iF}^Z(b)\, h_2(b,F) + Q_{iU}^Z(b)\, h_2(b,U)$$

When demand is favourable (ie in state F),
the optimal bandwidth adjustment policy during period 2 is

$$Z = \begin{cases} 1 & if \quad a_F^1(b) < a_F^0(b) \\ 0 & if \quad a_F^1(b) \geq a_F^0(b) \end{cases}$$

The associated operational costs are then

$$h_2(b,F) = \begin{cases} a_F^1(b) & if \quad Z = 1 \\ a_F^0(b) & if \quad Z = 0 \end{cases}$$

Similarly, when demand is unfavourable (ie. in state U), the optimal bandwidth adjustment policy during period 2 is

$$Z = \begin{cases} 1 & if \quad a_U^1(b) < a_U^0(b) \\ 0 & if \quad a_U^1(b) \geq a_U^0(b) \end{cases}$$

The associated operational costs are then

$$h_2(b,U) = \begin{cases} a_U^1(b) & if \quad Z = 1 \\ a_U^0(b) & if \quad Z = 0 \end{cases}$$

V. A Case Study about Zion and Computech Cybercafes in Uganda

In order to demonstrate use of the model in §3-4, a case study from Zion Cybercafe and Computech cybercafe in Uganda is presented in this section. Customer demand for internet service fluctuates every week based on the bandwidth and speed realised at the two cybercafes. The goal of managers at both cafes is to minimize operational costs when demand for internet service is favourable (state F) or unfavourable (state U) and hence, decision support is sought in terms of an optimal bandwidth adjustment policy and the associated operational costs for offering internet service in a two-week planning horizon.

Samples of customers, demand (in minutes) of internet service were collected. The state transitions of demand and the respective bandwidth adjustment policies were examined over twelve weeks. The data is presented in Tables 1-2.

Table 1: Customers versus state-transitions at Cybercafes

		Adjustment policy 1		Adjustment policy 0	
Cybercafe (b)	State of Demand (i)	F	U	F	U
Zion (1)	F	18	3	16	2
	U	13	8	10	4
Computech (2)	F	15	6	11	7
	U	10	8	9	5

Table 2: Demand (in minutes) versus state-transitions at Cybercafes

		Adjustment policy 1		Adjustment policy 0	
Cybercafe (b)	State of Demand (i)	F	U	F	U
Zion (1)	F	5000	800	3500	1500
	U	750	1000	1350	1050
Computech (2)	F	4800	1500	1500	2500
	U	2000	3000	1200	1050

For any chosen bandwidth adjustment policy at a given cybercafe, the unit operational cost (c_0) = US$ 0.0080 per minute

5.2 Computation of Model Parameters

Using (5) and (6), the state-transition matrices and operational cost matrices (in US$) were as follows for the case when the bandwidth was adjusted (Z=1) during week 1:

$$Q^1(1) = \begin{bmatrix} 0.857 & 0.143 \\ 0.684 & 0.316 \end{bmatrix} C^1(1) = \begin{bmatrix} 40 & 6.4 \\ 6 & 8 \end{bmatrix}$$

$$Q^1(2) = \begin{bmatrix} 0.714 & 0.286 \\ 0.556 & 0.444 \end{bmatrix} C^1(2) = \begin{bmatrix} 38.4 & 12 \\ 16 & 24 \end{bmatrix}$$

While these matrices for the case when bandwidth was not adjusted (Z=0) during week 1 are given by

$$Q^0(1) = \begin{bmatrix} 0.889 & 0.111 \\ 0.714 & 0.286 \end{bmatrix} C^0(1) = \begin{bmatrix} 28 & 12 \\ 10.8 & 8.4 \end{bmatrix}$$
$$Q^0(2) = \begin{bmatrix} 0.611 & 0.389 \\ 0.643 & 0.357 \end{bmatrix} C^0(2) = \begin{bmatrix} 12 & 20 \\ 9.6 & 8.4 \end{bmatrix}$$

Using (6) and considering bandwidth adjustment options available, the expected operational costs(in US$) are calculated for the given states of demand (in minutes) and results are presented in Table 3.

Table 3: Expected Operational costs for bandwidth adjustment options and states of demand at cybercafes

Cybercafe (b)	State of demand (i)	Expected operational costs $e^{Z}_{i}(b)$	
		Z=1	Z=0
Zion (1)	F	35.195	26.224
	U	6.632	10.114
Computech (2)	F	30.850	15.112
	U	19.552	9.172

Using (3) and considering bandwidth adjustment options available, the accumulated operational costs(in US$) are calculated for the given states of demand (in minutes) and results are presented in Table 4.

Table 4: Accumulated Operational costs for bandwidth adjustment options and states of demand at cybercafes

Cybercafe (b)	State of demand (i)	Accumulated operational costs $a^{Z}_{i}(b)$	
		Z=1	Z=0
Zion (1)	F	58.857	50.802
	U	26.856	30.935
Computech (2)	F	44.263	33.886
	U	32.037	28.582

5.3 The Optimal Bandwidth Adjustment Policy and operational costs at cybercafes
Using results from Table 3, the optimal bandwidth adjustment policy and expected operational costs are determined at cybercafes during week 1.

Zion cybercafe

Since 26.224<35.195, it follows that Z=0 is an optimal bandwidth adjustment policy for week 1 with associated expected operational costs of 26.224 US$ for the case of favourable demand. Since 6.632<10.114, it follows that Z=1 is an optimal bandwidth adjustment policy for week 1 with associated expected operational costs of 6.632 US$ for the case of unfavourable demand.

Computech cybercafe

Since 15.112< 30.850, it follows that Z=1 is an optimal bandwidth adjustment policy for week 1 with associated expected operational costs of 15.112US$ for the case of favourable demand. Since 9.172<19.552, it follows that Z=0 is an optimal bandwidth adjustment policy for week 1 with associated expected operational costs of 9.172US$ for the case of unfavourable demand.

Using results from Table 4, the optimal bandwidth adjustment policy and accumulated operational costs are determined at cybercafes during week 2.

Zion cybercafe
Since 50.802<58.857, it follows that Z=0 is an optimal bandwidth adjustment policy for week 2 with associated accumulated operational costs of 50.802 US$ for the case of favourable demand. Since 26.856<30.935, it follows that Z=1 is an optimal bandwidth adjustment policy for week 2 with associated accumulated operational costs of 26.856 US$ for the case of unfavourable demand.

Computech cybercafe
Since 33.886 < 44.263, it follows that Z=0 is an optimal bandwidth adjustment policy for week 2 with associated accumulated operational costs of 33.886US$ for the case of favourable demand. Since 28.582<32.027, it follows that Z=0 is an optimal bandwidth adjustment policy for week 2 with associated accumulated operational costs of 28.582US$ for the case of unfavourable demand.

VI. Conclusions and Discussion

The choice of an optimal bandwidth adjustment policy for providing internet service in cybercafes at least cost can be modelled as a markov decision process problem under stochastic stationary demand. Using dynamic programming, the decision of whether or not to adjust the bandwidth for faster internet service at optimal costs is made over a finite period planning horizon. Results from the model indicate optimal state-dependent bandwidth adjustment policies and costs at the two cybercafes considered in the study. As a cost minimization strategy for internet service provision at cybercafes, computational efforts of using Markov decision process approach provide promising results. Further extensions of the research are however sought in order to consider a considerable number of cybercafes; as well as the effect of non stationary demand on bandwidth adjustment policies. The model developed raises a number of salient issues to consider that affect operations of cybercafes: power disruptions in offering internet service, customer response to abrupt changes in price and speed of internet service. Special interest is also sought in further extending the model by considering adjustment policies for optimal costs using continuous time markov chains. As noted in the study, cost comparisons were vital in determining the optimal bandwidth adjustment policy. In addition, classification of demand as a two-state Markov chain facilitated modeling and optimization of bandwidth adjustment policies for the specific case study considered.

VII. ACKNOWLEDGEMENTS

The authors would like to thank the staff of Zion and Computech cybercafes whose data contributed to the stage of testing the developed model.

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Cite this article as :

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Kizito Paul Mubiru, Senfuka Christopher, Maureen N. Ssempijja, "Optimization of Cybercafe Internet Service and Costs under Stochastic Demand", International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), Online ISSN : 2394-4099, Print ISSN : 2395-1990, Volume 6 Issue 3, pp. 93-99, May-June 2019. Available at doi : https://doi.org/10.32628/IJSRSET1962158
Journal URL : http://ijsrset.com/IJSRSET1962158