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Optimal Medical Equipment Maintenance Service Proposal Decision Support System combining Activity Based Costing (ABC) and the Analytic Hierarchy Process (AHP)

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Abstract— **This study describes a framework to support the choice of the maintenance service (in-house or third party contract) for each category of medical equipment based on: a) the real medical equipment maintenance management system currently used by the biomedical engineering group of the public health system of the Universidade Estadual de Campinas located in Brazil to control the medical equipment maintenance service, b) the Activity Based Costing (ABC) method, and c) the Analytic Hierarchy Process (AHP) method. Results show the cost and performance related to each type of maintenance service. Decision-makers can use these results to evaluate possible strategies for the categories of equipment.**

Index Terms— **Clinical engineering, state-diagram**

I. Introduction

A biomedical engineering (BME) group comprises the engineers that support and advance patient care by applying engineering and managerial skills to healthcare technology [1]. The explanation of the importance of this group to the medical institution's success is the diversification of services delivered to the hospital such as technology assessment, technology acquisition, research and development of instrumentation and control of the technology maintenance. The focus on the control of the medical devices and equipment maintenance presents the advantages of the minimization of equipment failure, the improvement of equipment safety, and the reduction of equipment downtime. Generally, decision-makers must deal with the choice of types of maintenance service (in-house or third party contract) according to each category of equipment. As the manner of doing the service affect its cost and each activity of a process is a description of how service is performed, the cost of service depends on all activities necessary to perform it. It means that, the cost of service can be used to support the decision making between in-house and third party maintenance service, since the cost of maintenance service is a function of activities performed for each type of service order. As Analytic Hierarchy Process (AHP) is a decision making method in which multi-criteria are considered for prioritizing alternatives in meeting a specific goal [2], this study describes a framework based on a real medical equipment maintenance management system, the Activity Based Costing (ABC) method [3], and the AHP to support the choice of the maintenance service for each category of medical equipment.

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II. Methodology

The Center for Biomedical Engineering (CEB) manages and performs maintenance of medical equipment of the public health system of the Universidade Estadual de Campinas (UNICAMP), located in the state of Sao Paulo, Brazil. The university's medical area comprises a School of Medicine, a five hundred bed general hospital, a one hundred bed women's hospital and around ten medical centers. The medical equipment inventory adds more than ten thousand equipment ranging from sphygmomanometers to complex systems, such as CT and MRI. The diagram in Fig. 1 shows the microprocess-controlled maintenance management system currently used in CEB [4]. Each code refers to a specific microprocess that is activated according to the condition of the service order. The service cost centers involved in the maintenance service are Customer Care Center (CAC), Finances and Supplies (SUP), Clinical Engineering Manager (GEC), Clinical Engineers (GRU), and Technical Staff (EXE). Each service cost center is responsible for performing the activated microprocess and setting the next condition. CAC performs the microprocesses AV (EXE is waiting equipment to arrive in biomedical shop), CG (equipment is under guarantee), EP (service done), OU (higher level administrative decision is required to proceed), VT (third party technician called for on site repair or advice), and OA (service order call), SUP performs the microprocesses AI (acquisition of spare parts), AS (budget is authorized by SUP), and SU (purchase performed by the medical area unity), GEC performs the microprocesses AO (GEC is waiting for budget), AR (equipment is waiting for removal by third party contractor), DP (proposal of inactivation of equipment), and EX (service order executed at third party companies), GRU performs the microprocesses AT (GRU is waiting for authorization from SUP) and AE (place service order on waiting list), and EXE performs the microprocess EE (perform the maintenance). Each transition between two microprocesses corresponds to one activity. And finally, each allowed trajectory from service order call (OA) to service order completion (CO) corresponds to a different type of service order. For example, the trajectory in bold corresponds to most frequent service order, which has the following activities: OA-AE, AE-EE, EE-EP, and EP-CO.

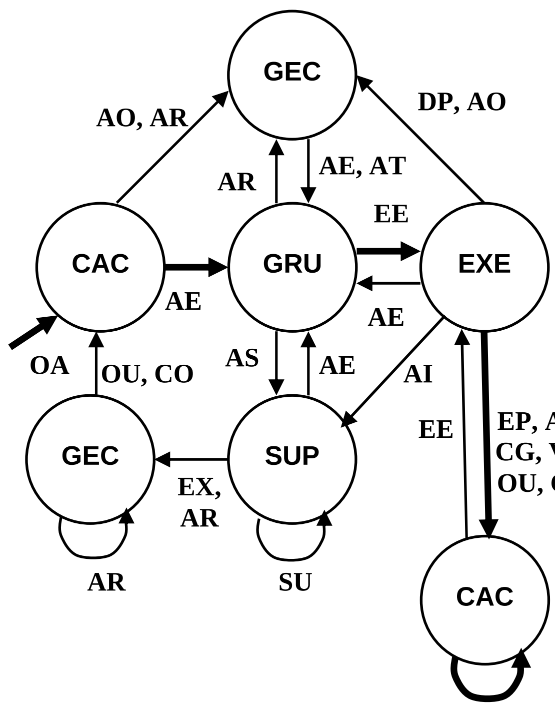

Fig. 1. State-diagram management system at CEB-UNICAMP.

Fig. 2 shows the model to link state-diagram and activity based costing, in which we can see the yearly spending accumulated in service cost centers and the activities. Costs (such as salaries, depreciation, and general expenses) are allocated to activities through the so called cost driver, which is a function that outputs the total time spent to perform all transitions in each service cost center [5]. Cost of service order is determined by adding up costs for all transitions performed within a specific trajectory [6]. Fig. 3 and Fig.4 present a framework that ties maintenance service decisions (in-house maintenance or third party contract maintenance service) to activity based costing plus performance measures using analytic hierarchy process [7]. Service orders # 1 and # 2 have respectively the following sequences of transitions: OA-AE-EE-CO (maintenance done on site) and OA-AE-EE-VT-AE-EE-CO (maintenance done on site after calling third party technician for repair or advice).

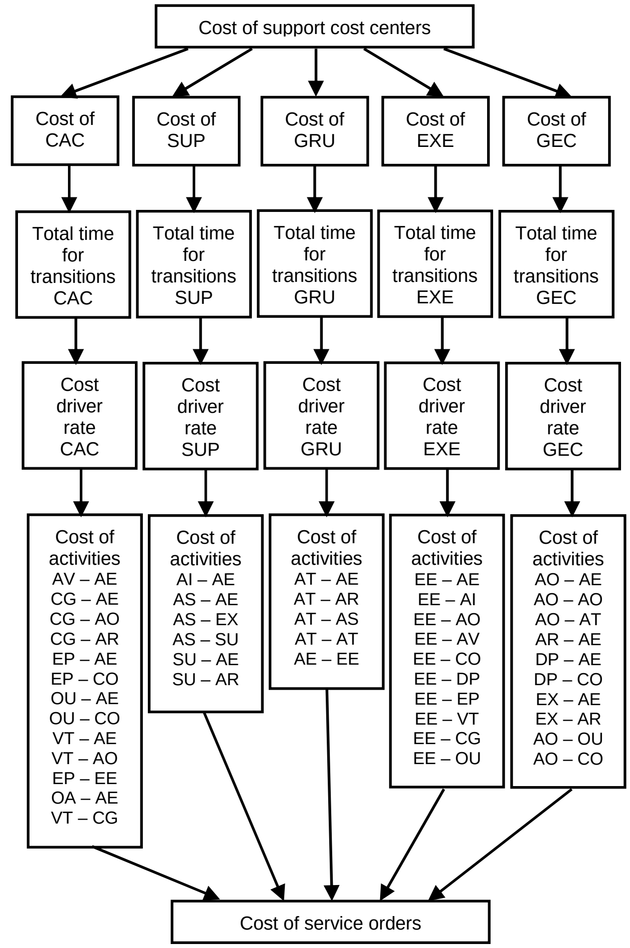

Fig. 2. Activity based costing applied to the CEB-UNICAMP.

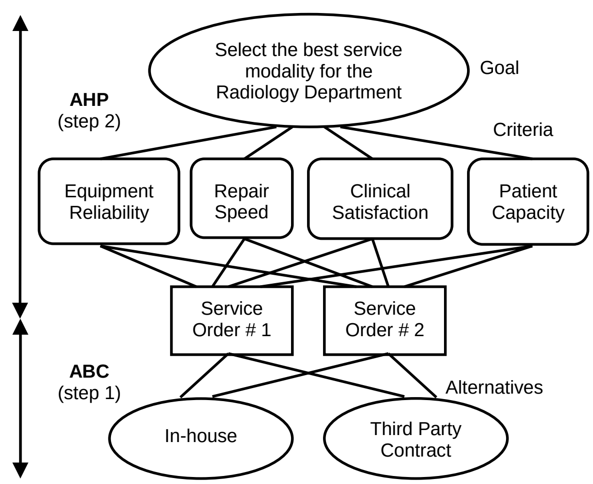

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Fig. 3. Cost model for selecting the best maintenance service modality.

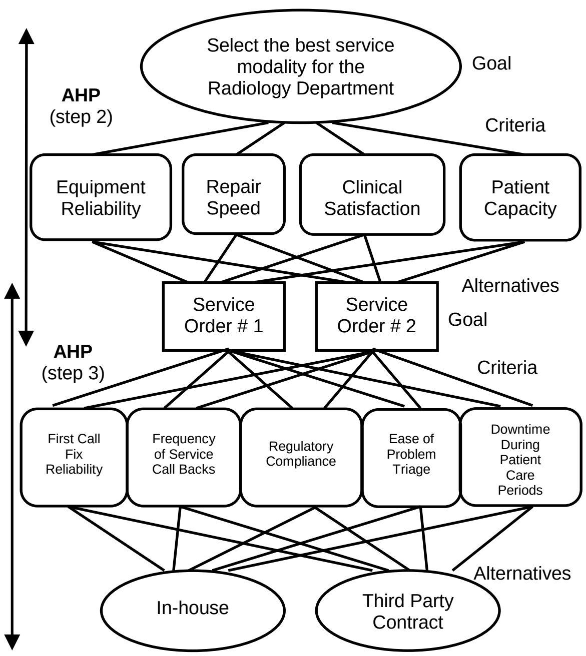

Fig. 4. Performance model for selecting the best maintenance service modality.

III. Results

Tables I, II, and III show the results that were calculated using ABC in the step 1 of Fig. 3 applied to both 4 radiographic units and 1 CT. The cost of activity equals the average time (AT) of each transition multiplied by the cost driver rate (CDR) of the cost center that performed it. Table IV shows the service order weights in achieving the goal that resulted from the step 2 of Fig. 3. These weights were calculated using the software Expert Choice 2000 [8].

TABLE I
Expenditure for Cost Centers, Cost Drivers, and Cost Driver Rates Proportional to 4 Radiographic Units and 1 CT - Year 2003

Equip.	*Cost center*	*Cost driver (day)*	*In-house*		*Third party*	
			Expenditure (R$)	*CDR (R$/day)*	*Expenditure (R$)*	*CDR (R$/day)*
4 Rad. Units	CAC	488.26	3,285.99	6.73	3,828.33	7.84
	SUP	153.5	1,607.15	10.47	0	0
	GRU	114.5	494.64	4.32	23,202.00	202.64
	EXE	36.5	2,082.33	57.05	11,601	317.84
	GEC	0	0	11.11	34,803.00	-
1 CT	CAC	54.028	363.61	6.73	1,908.05	35.32
	SUP	0	0	10.47	0	-
	GRU	7.0	30.24	4.32	11,563.92	1,651.99
	EXE	6.5	370.83	57.05	5,781.96	889.53
	GEC	32.0	355.52	11.11	17,345.88	542.06

TABLE II
Cost of Service Orders to 4 Radiographic Units

Activity	*In-house*				*Third party*			
	AT (day)	*CDR (R$/day)*	*Cost of service order (R$) # 1*	*# 2*	*AT (day)*	*CDR (R$/day)*	*Cost of service order (R$) # 1*	*# 2*
OA-AE	0.004	6.73	0.03	0.03	0.004	7.84	0.03	0.03
AE-EE	1.15152	4.32	4.97	9.94	1.15152	202.64	233.34	466.68
EE-CO	0.30769	57.05	17.55	17.55	0.30769	317.84	97.80	97.80
EE-VT	0.5	57.05	-	28.53	0.5	317.84	-	158.92
VT-AE	16.43478	6.73	-	110.61	16.43478	7.84	-	128.85
			22.55	166.66			331.17	852.28

TABLE III
Cost of Service Orders to 1 CT

Activity	*In-house*				*Third party*			
	AT (day)	*CDR (R$/day)*	*Cost of service order (R$) # 1*	*# 2*	*AT (day)*	*CDR (R$/day)*	*Cost of service order (R$) # 1*	*# 2*
OA-AE	0.004	6.73	0.03	0.03	0.004	35.32	0.14	0.14
AE-EE	0.5	4.32	2.16	4.32	0.5	1,651.99	826.00	1,652.00
EE-CO	0.5	57.05	28.53	28.53	0.5	889.53	444.77	444.77
EE-VT	0.5	57.05	-	28.53	0.5	889.53	-	444.77
VT-AE	10.8	6.73	-	72.68	10.8	35.32	-	381.46
			30.72	134.09			1,270.91	2,923.14

TABLE IV
Service Orders Weights of Both In-house and Third Party Company to 4 Radiographic Units and 1 CT

Service order	*Service order weight*
# 1	0.577
# 2	0.423

The cost of each maintenance service modality related to the integration of steps 1 and 2 in Fig. 3 was calculated using Equation (1) below:

$$\text{cost} = \text{service order \#1 weight} \times \text{cost of service order \#1} + \\ + \text{service order \#2 weight} \times \text{cost of service order \#2} \quad (1)$$

Table V, below, shows results from the cost model for selecting the best maintenance service modality:

TABLE V
Cost of In-house and Third Party Maintenance Service to 4 Radiographic Units and 1 CT

Equipment	*Cost of the maintenance service (R$)*	
	In-house	*Third Party*
4 Rad. Units	83.51	551.60
1 CT	74.45	1,969.80

The service order weights in achieving the goal in the step 2 of Fig. 4 equal the results that were shown in Table IV.

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Table VI shows the criteria weights that were calculated in the step 3 of Fig. 4 using the software Expert Choice 2000 as well as the ratings for criteria of both the in-house and the third party maintenance service considering each type of service order.

TABLE VI
CRITERIA WEIGHTS AND RATINGS FOR EACH CRITERION OF BOTH IN-HOUSE AND THIRD PARTY MAINTENANCE SERVICE TO 4 RADIOGRAPHIC UNITS AND 1 CT

Criterion	*Service order # 1*			*Service order # 2*		
	Criterion weight	*Rating*		*Criterion weight*	*Rating*	
		In-house	*Third party*		*In-house*	*Third party*
First call fix reliability (criterion 1)	0.411	0.3	0.7	0.411	0.3	0.7
Frequency of service call backs (criterion 2)	0.279	0.4	0.6	0.279	0.5	0.5
Regulatory compliance (criterion 3)	0.201	0.5	0.5	0.201	0.5	0.5
Ease of problem triage (criterion 4)	0.064	0.5	0.5	0.064	0.5	0.5
Downtime during patient care periods (criterion 5)	0.045	0.4	0.6	0.045	0.5	0.5

Performance of each maintenance service modality which is resulted from the integration of steps 2 and 3 in Fig. 4 was calculated using Equations (2) and (3) below. The value of each criterion in (2) and (3) is calculated as before, using Equation (4), in which n varies from 1 to 5.

$$\begin{aligned}&\text{performance of the in-house maintenance service} =\\ &= \sum \text{criterion } n \times \text{rating for criterion } n \text{ to in-house service order \# 1} +\\ &+ \sum \text{criterion } n \times \text{rating for criterion } n \text{ to in-house service order \# 2}\end{aligned} \quad (2)$$

$$\begin{aligned}&\text{performance of the third party maintenance service} =\\ &= \sum \text{criterion } n \times \text{rating for criterion } n \text{ to third party service order \# 1} +\\ &+ \sum \text{criterion } n \times \text{rating for criterion } n \text{ to third party service order \# 2}\end{aligned} \quad (3)$$

$$\begin{aligned}&\text{criterion } n = \text{service order \# 1 weight} \times \text{criterion } n \text{ weight} +\\ &+ \text{service order \# 2 weight} \times \text{criterion } n \text{ weight}\end{aligned} \quad (4)$$

Table VII shows results from the performance model for selecting the best maintenance service modality.

TABLE VII
PERFORMANCE OF IN-HOUSE AND THIRD PARTY MAINTENANCE SERVICE TO 4 RADIOGRAPHIC UNITS AND 1 CT

Performance of the maintenance service	
In-house	*Third Party*
0.8032	1.1968

Fig. 5 shows the results of the cost and performance model for selecting the best service modality for 1 CT and 4 radiographic units in the Radiology Department. Firstly, the results from Table V and VII were normalized. Secondly, these results were plotted on graphs in Fig. 5. Finally, a Cost Performance Ratio (CPR) and Net Cost Performance Ratio (NCPR) can be computed from the normalized values (e.g., For the 3rd Party CT case, CPR(Third party)$_{CT}$ =Perfomance/Cost = 0.5984/0.9636 ≅ 0.6; CPR(In-house)$_{CT}$ ≅ 11.0271; and, thus, the NCPR(In-house)$_{CT}$ ≅ 11.0271/0.6210 =17.76). As the NCPR(In-house)$_{Rad}$ ≅ 4.43, this suggests that the relative benefit of In-house servicing the CT is about 4 times better than servicing the Rad Units.

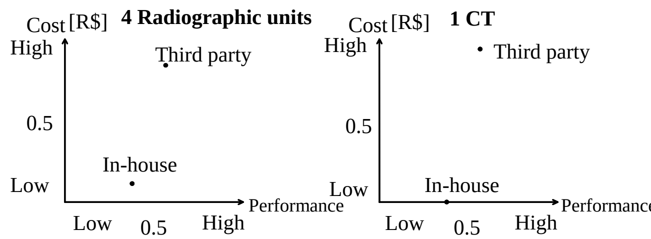

Fig. 5. Cost and performance model for selecting the best maintenance service modality.

IV. CONCLUSION

This study described a framework to evaluate two maintenance service modalities for medical equipment.

The costs of service orders # 1 and # 2 that were calculated using in-house expenditure to both 4 radiographic units and 1 CT are lower than the costs of service orders # 1 and # 2 that were calculated using third party expenditure (see Tables II and III). Besides, the cost of the maintenance service modality favors in-house maintenance service to both 4 radiographic units and 1 CT (see Table V). However, results from performance model (see Table VII) in which performance measures are first call fix reliability, frequency of service call backs, regulatory compliance, ease of problem triage, and downtime during patient care periods, slightly favor third party maintenance service to both radiographic units and 1 CT.

The NCPR(In-house)$_{CT}$ is much better than the NCPR(In-house)$_{Rad}$. If the In-house performance levels are acceptable, then the hospital would wisely make In-house CT service a first priority.

Future research using this model could explore sensitivity analyses, risk/benefit ratios, and integration with other Clinical Engineering management decision tools.

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