CAPACITY DECISIONS FOR AN EMERGENCY SERVICE

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Decision makers face two opposing forces in the provision of emergency services. Their constituency wants more and better services, but financial considerations limit the quantity and quality of services provided. This classic economic confrontation requires a decision based on the trade-offs between the benefits of protection provided by additional services and the cost of providing these services. Such a decision is needed for ambulance service, fire protection, and law enforcement.

Ideally, decision makers would like to provide emergency system capacity adequate for the worst catastrophe. However, as no budget will permit such a system, they must determine how much service capacity to provide. The objective of this article is to derive and illustrate a technique which can be used to estimate the number of times per year an emergency service will be unable to respond when needed because its units are employed on other emergencies. The technique is illustrated by application to an ambulance service in a rural Oklahoma county. Information obtained by use of this technique, combined with a budget analysis, will enable local decision makers to estimate the need for and cost of additional ambulance capacity.

METHOD

The general model of queueing theory can be used to determine the probability that the number of demanders for an emergency service will exceed the capacity to provide this service. The derivation of this general model can be found in [2, p. 38-40] and in other introductory queueing theory texts.

The basic model assumes an average arrival rate at the service point of v, and an average service rate of u. If the maximum queue length is n, then the following equations, known as the Erlang equations, can be derived.

(1) $O = vP_{k-1} + uP_{k+1} - (u+v)P_k \quad k=1,2,...,n-1$

(2) $O = uP_1 - vP_O$

(3) $O = vP_{n-1} - uP_n$

where P_k is the probability that there will be k persons in the queue. From equation 2,

$$P_1 = \frac{v}{u} P_O$$

which when substituted into equation 1 yields

$$P_2 = (\frac{v}{u})^2 P_O$$

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$$P_k = (\frac{v}{u})^k P_O$$

At this point define $p \equiv \frac{v}{u}$, which is generally called the traffic intensity ratio. Because the probabilities must sum to one, for a queue with no maximum length the probability of having k or more persons in the system when only k−1 can be served is

$P(\geqslant k) = 1 - P_O - P_1 - ... - P_{k-1}$

(4) $\quad = 1 - (1-p) - (1-p)p - ... - (1-p)p^{k-1}$

$\quad = p^k.$

The decision maker supposedly is willing to accept a probability, α, of a person requiring emergency service when all servers are occupied. For an emergency service with k−1 servers

$$\alpha = P(\geqslant k).$$

Then

(5) $$p^* = \alpha^{1/k},$$

where p^* is the traffic intensity ratio associated with this α.

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AN APPLICATION

The community leaders of Alfalfa County, Oklahoma, were forced to provide ambulance service when the private suppliers refused to continue the service. The leaders were not only confronted with the expensive problem of providing one complete ambulance, but also had to decide whether a back-up ambulance was needed for a multiple injury accident or overlapping requests for service. Alfalfa County has a population of 7,224; the town of Cherokee with 2,119 residents is in the center of the county.[1] A small hospital is located in Cherokee.

A calculation procedure developed by Doeksen, Frye, and Green [1] indicated that 335 calls per year could be expected for the county system. In addition, an analysis of the previous year's calls revealed an average round trip service time of 77.9 minutes. An estimate of the service rate, u, can be calculated as (60 min/hr)/(77.9 min/call) = 0.7702 calls handled per hour.

The same method can be used to derive the annual number of calls consistent with a given probability of the queue length exceeding the number of service facilities. A similar method determines the expected probability of capacity being exceeded associated with a given number of annual calls.

Suppose the community leaders are willing to accept at most a probability of one occurrence per year that more than one patient will require the ambulance at the same time, i.e., for the 335 calls expected $\alpha = 1/335$. For a single ambulance system, k = 2, and from equation 5, this probability has an associated traffic intensity ratio, p*, of 0.0546. Solving for v from the traffic intensity ratio formula, one obtains $v = p^*u = (0.0546)(.7702) = 0.0421$. The mean arrival rate for service is 0.0421 calls per hour, which translates into 1.01 calls per day or 369 calls per year, slightly more than the 335 expected calls estimated previously.

By a reverse method, given that the estimated number of calls is 335 per year, the average arrival rate $v = (335)(1/365)(1/24) = 0.03824$ calls per hour. As before u is 0.7702. Substituting into equation 4, one obtains

$$P(\geq 2) = p^2 = \left(\frac{0.03824^2}{0.7702}\right) = 0.00247.$$

This probability is approximately one occurrence in every 400 calls.

To weigh the trade-offs associated with overlapping demand, the decision makers must know the costs of providing a back-up unit. Table 1 shows budgets for the main ambulance, a new ambulance as a back-up unit, and a used ambulance as a back-up unit. This budget information is taken from [1] and is updated to present prices. It is based on the assumption of a hospital-based system with four Emergency Medical Technicians (EMT) and a Licensed Practical Nurse or a Registered Nurse accompanying the ambulance on calls. It is assumed that if a back-up is provided, one of the EMTs will be on call during each eight hours of the day and will be paid $5 for being on call. Pocket pagers are provided to allow the EMT freedom of movement within town.

Estimated yearly costs for providing a one-ambulance system with the ambulance replaced after 75,000 miles or every three years would be $39,053 (Table 1). If the decision makers provide a new back-up unit, mileage could be alternated between the vehicles and each would last six years. Thus, additional yearly capital depreciation because of the back-up would be much less than for the original ambulance. In either case many of the operating expenses can be allocated between vehicles. The main additional charge for the back-up unit is labor costs. Total yearly costs under these conditions for a new back-up unit are $8,760. If a used ambulance is purchased as a back-up unit for $3,000 and is depreciated over three years, then total yearly costs are $7,930.

TABLE 1. ANNUAL BUDGET FOR FIRST-RUN AMBULANCE AND FOR BACK-UP AMBULANCE

		Back-Up Ambulance	
	First-Run Ambulance	New Ambulance	Used Ambulance
Equipment Expenses			
Depreciation-ambulance	$ 5,272	$ 500	$1,000
Depreciation-communication	165	165	165
Depreciation-pagers	0	200	200
Interest	1,440	1,520	240
Insurance	500	500	250
Subtotal	$ 7,377	$2,885	$1,855
Operating Expenses			
Vehicle	2,401	300	500
Communication	50	100	100
Medical	521	0	0
Subtotal	$ 2,972	$ 400	$ 600
Labor	$28,704	$5,475	$5,475
Total	$39,053	$8,760	$7,930

[1] 1970 Census population estimates. Population has changed very little since 1970.

The extra costs for a back-up unit do not appear to be large until they are compared with revenue for the system. For Alfalfa County, assuming a charge of $25 per call plus $1 per mile one way with 80 percent of the users paying their bill, approximately $18,000 is received each year. Thus, the one-unit system incurs an approximately yearly loss of $21,000 without a back-up unit. The cost for the back-up unit would increase the yearly loss about $8,000.

The back-up ambulance can reduce the probability of overlapping need for the available ambulance from approximately once every 400 calls to approximately once every 8000 calls, i.e., $P(\geq 3)$. Whether this protection is worth $8,000 is the decision the local people must make. The back-up unit, in addition to providing reserve coverage for overlapping calls, provides coverage during down time for the primary ambulance and may generate some revenue from interhospital transfers or other nonemergency uses which would otherwise be foregone. Such uses are rare, however, and would not basically change the fiscal situation.

SUMMARY AND CONCLUSIONS

The method illustrated can be used to derive the annual number of calls consistent with a given probability that the number of service demanders will exceed the number of service facilities. A reverse method can be used to determine the expected probability of capacity being exceeded associated with a given number of annual calls. In either case, beginning with an estimate of average service time, an objective procedure can be applied to a decision that otherwise would be very subjective. As local decision makers continue to be urged to provide additional emergency services in rural areas, information from this technique, in conjunction with budgets and models to predict usage, will be extremely useful in rural decision making.

REFERENCES

[1] Doeksen, Gerald A., Jack Frye, and Bernal L. Green. *Economics of Rural Ambulance Service in the Great Plains*, USDA, ERS, Agricultural Economics Report No. 308, November 1975.

[2] Saaty, Thomas L. *Elements of Queueing Theory with Applications.* New York: McGraw-Hill Book Company, Inc., 1961.