

# Resource Reallocation in an Emergency Medical Service System Using Computer Simulation

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**Emergency medical service (EMS) policy makers must seek to achieve maximum effectiveness with finite resources. This research establishes an EMS computer simulation model using eM-Plant software. The simulation model is based on Taipei city's EMS system with input data from prehospital care records from December 2000; it manipulates resource allocation levels and rates of idle errands. Presently, EMS ambulance utilization is about 8.78%. On average, 20.89 minutes are required to transport a patient to the hospital. Computer simulations showed that reducing the number of ambulances to one at each of the 36 response units increases the utilization rate to 15.47% but does not compromise the current service quality level. Thus, ambulance utilization improves, times of patients waiting for pre-hospital care and arrival at hospitals are only slightly affected, and considerable cost savings result. This study provides a research methodology and suggests specific policy directions for resource allocation in EMS. Limiting the number of ambulances to one per response unit reduces costs, increases efficiency, and yet maintains the same operational pattern of medical service. (Am J Emerg Med 2002;20:627-634. Copyright 2002, Elsevier Science (USA). All rights reserved.)**

Prehospital care is an important aspect of modern medical care, and much literature has shown that effective prehospital care can reduce patient mortality and morbidity.<sup>1-7</sup> However, what is considered the best emergency medical service (EMS) pattern is still controversial. Individual countries or regions have developed their own specific EMS models based on their own resource availability and specificity. This is especially true for developing countries, which must establish complex ambulance transportation systems to provide emergency medical services. However, regardless of the kind of EMS system, the expense is considerable.<sup>1-4,7-9</sup> Therefore, developing and providing emergency medical services that are both cost-effective and meet a population's needs under limited resources are primary concerns of many policy makers.

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The United States has been developing its emergency medical services system since 1970. In 1973, the Emergency Medical Services Act defined emergency medical services as "[a] system that provides for the arrangement of personnel, facilities, and equipment for the effective and coordinated delivery of health care services under emergency conditions and that is administered by a public or non-profit entity with authority and the resources to provide effective administration of the system."<sup>10</sup> The government of Taiwan enacted ambulance management rules in 1981 and began to develop the system for EMS. In 1995, the government enacted the Emergency Medical Services Law, which became the basis for prehospital emergency care.

This current research proposes a management system for emergency medical services, using computer simulation to evaluate the performance of the EMS system and explore alternatives for reducing costs while providing better or equal quality of care.

## MATERIALS AND METHODS

### Taiwan's EMS System

Most areas of Taiwan use a tier rescue model that is staffed mainly with level 1 or level 2 emergency medical technicians (EMTs) and is generally administered by the fire department. Level 2 EMTs receive more advanced training than level 1 EMTs and are used in the 2-tier model. (The 2-tier model dispatches 2 ambulances to the scene: one providing basic life support and one providing advanced life support. The 1-tier model dispatches one ambulance rescue team providing basic life support.) Taiwan's predominant model is the 1-tier EMS model, which is mainly staffed with basic EMTs (level 1). Services provided by EMTs cover emergency management and care of automobile accidents, traumas, critical diseases, and accidental poisonings.

### Taipei's Emergency Medical Services System

This research takes Taipei's emergency medical services system (TEMSS) as its subject, seeking possible alternatives to improve the system's effectiveness and to limit costs. Taipei's EMTs system has 36 response units (named in this paper as subgroups EMS1-EMS36) located along with 36 fire departments. Each response unit has available 1 to 3 staffed ambulances (ambulance rescue teams). One headquarters assigns incoming rescue calls to the nearest of 2 to 4 response units in 12 administrative area. The steps and methods are as follows.

*Clarification of the flowchart.* To clarify the exact process of the prehospital emergency medical care system in Taipei (Fig 1), interviews were conducted with individuals

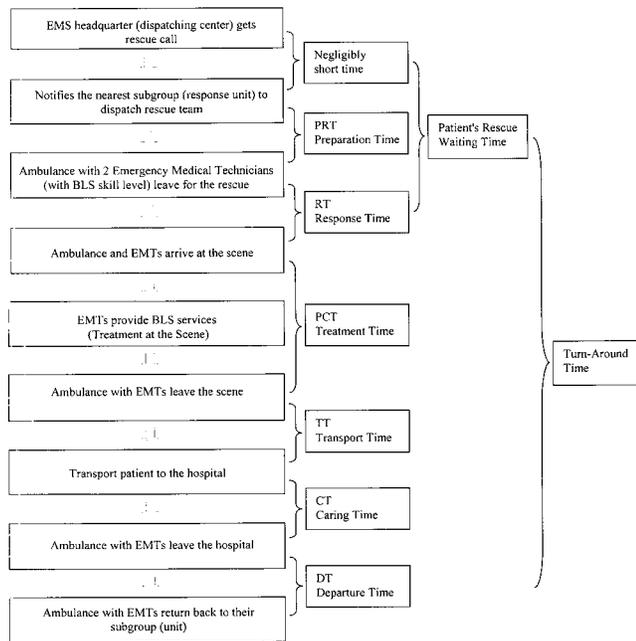


FIGURE 1. Time intervals for 1-tier rescue pattern.

familiar with the TEMSS. The flowchart progression is as follows. When the headquarters gets calls for help, the dispatcher notifies generally the nearest of 36 emergency service response units to perform the rescue based on the incident's address proximity. Every emergency service response unit is staffed with 1 to 3 rescue teams and is available for service 24 hours a day. Each rescue team is composed of 1 ambulance and 2 EMTs. After the EMTs arrive at the scene and perform primary assessment and treatment, they transport the patient to the closest hospital that can provide further emergency care. The emergency medical service team is dismissed after it has reported the patient's situation to the hospital's medical personnel. It then returns to the subgroup and waits for its next mission. If a rescue event occurs in a response unit's area of responsibility and 1 team is already in service, another rescue team must take this mission. If there is no other team available in the response unit, the headquarters asks the next nearest response unit to take the mission. Because this study explores the appropriateness of resource allocation for the TEMSS, the relatively small number of 2 simultaneous calls for help is neglected.

**Data collection and analysis.** The following rescue records of the TEMSS dated from December 1, 2000 to December 31, 2000 were collected for analysis: (1) the name of response unit performing the rescue; (2) classification of the rescue cause (eg, trauma, nontrauma illness, or prehospital cardiac arrest); and (3) the times for the following rescue segments: dispatch headquarters notified, subgroup unit notified, ambulance rescue team responds, ambulance rescue team arrives at the scene, ambulance rescue team leaves the scene, ambulance rescue team arrives at the hospital, ambulance rescue team leaves the hospital, and ambulance rescue team is back in service.<sup>11</sup>

For each rescue, the time interval between consecutive segments was counted to determine the following: prepara-

tion time (PRT, interval between the time the headquarters gets the rescue call, notifies a nearest subgroup and the time it responds by sending an ambulance rescue team), response time (RT, interval between the time the ambulance rescue team responds and the time it arrives at the scene), processing time (PCT, interval between the time the ambulance rescue team arrives at the scene and the time it leaves the scene), transport time (TT, interval between the time the ambulance rescue team leaves the scene and arrives at the hospital), caring time (CT, interval between the time the ambulance rescue team arrives at the hospital and the time it leaves the hospital), and departure time (DT, interval between the time the ambulance rescue team leaves the hospital and the time it is back in service).

BestFit software<sup>12</sup> (Palisades Corp, Newfield, NY) was used to choose the best-fitting distributions of the above times. The distributions of each activity time were fed into the corresponding time distribution of the simulation model. The time interval between 2 successive, reported rescue event calls (event interarrival time) was counted and best fitted with the software again using data from the Taipei municipal fire department's dispatching records that showed the times the rescue calls were reported, the names of the response units were dispatched, and the final destinations (either the names of the destination hospitals or idle errands [ambulance departure from the subgroup and return to the subgroup without fulfilling a rescue, ie, false alarms]). Thereafter, the following input parameters were fed into the simulation model: (1) the events' interarrival time distribution, (2) the go-errand (total number of errands: true plus idle) proportion, and (3) the idle-errand proportion of each response unit.

**Simulation model design.** The fourth generation simulation software, eM-Plant (Tecnomatix Technologies, Ltd, Neu-Isenburg, Germany),<sup>13</sup> was used to develop the simulation model. This system is an entirely object-oriented program using object-oriented graphics and integrated modeling for simulating and visualizing systems and business processes. Its users have the following advantages: (1) they can build hierarchical models either bottom up or top down, (2) they can reuse submodels or parts of models stored in the engineering database, (3) they can use several modeling techniques for different levels to verify the results of each level and dramatically increase productivity, (4) they can centralize and define changes of all relevant system parameters in 1 table, and (5) they can integrate in real time with other software.

The subject's system flowchart is shown in Fig 1. Its input data were distributions of event interarrival time, preparation time, response time, processing time, transport time, caring time, and departure time or idle-errand time. The outcome variables were the utilization rates of each ambulance rescue team, each subgroup, and the patient's rescue waiting time (time between the rescue event report call and the rescue team's arrival. It includes preparation time plus response time). Different random number seeds were used to replicate the event 100 times to derive the outcome variables.

**Model validation and verification.** Model validation was performed by showing the model to emergency medical service specialists, who judged if the model ran the same way as the real-world system. Verification was conducted

by simulation programming specialists, who determined if the program logic and language were correctly written. More important, the established simulation model was validated by comparing the system’s empirical data with the simulation-derived data for the total number of events reported, processing (treatment) time at the scene, turnaround times, and total number of idle errands. (Turnaround time was counted as the time interval between ambulance departure from the subgroup unit and return to the unit. The time interval between rescue call and ambulance dispatch was so short [a few seconds] that it could be neglected.)

*Analysis of simulation results and proposed alternatives.* After making changes in the simulation parameters, the researcher ran the simulation model for 168 hours (1 week), using different random number seeds to replicate the outcomes 100 times and using the same method as the original

model. Then differences in the resulting alternatives were checked. Each alternative was analyzed for any marginal benefits it would contribute, and alternatives were suggested.

The attempted alternatives were as follows:

1. Reduction in the number of ambulance rescue teams per subgroup: based on the utilization rate of each ambulance rescue team and response unit, the resource allocation level may be modified. If a response unit utilization rate is low, personnel staffing and the number of ambulances may be reduced individually or in combination to determine their effect on the utilization rate without increasing the patients’ rescue waiting time.
2. Modification of the idle errand rate: idle errands (errands not resulting in reaching patients at the event

**TABLE 1.** Taipei’s EMS System Subgroups: Number of Ambulance Rescue Teams, Number of Errands, Percent of Dispatches, and Idle/True Errand Ratio

EMS Subgroups (Rescue Units)	Number of Ambulances (All Staffed with 1 Rescue Team)	Number of Go-Errand Calls (All Errands)	% of Dispatches per Subgroup as % of Total Dispatches for All 36 Subgroups	Rescue Dispatch Ratios (%)	
				Idle Errands (False Alarms)	True Errands (Transport Patients to Hospital)
EMS1	2	257	4.00	31.74	68.26
EMS2	2	153	2.38	34.38	65.63
EMS3	1	73	1.14	33.85	66.15
EMS4	1	92	1.43	21.25	78.75
EMS5	1	43	0.67	28.95	71.05
EMS6	2	149	2.32	28.36	71.64
EMS7	2	377	5.87	16.10	83.90
EMS8	2	109	1.70	27.85	72.15
EMS9	3	351	5.47	17.27	82.73
EMS10	1	130	2.03	32.76	67.24
EMS11	2	177	2.76	25.66	74.34
EMS12	2	147	2.29	30.95	69.05
EMS13	3	332	5.17	29.86	70.14
EMS14	2	94	1.46	29.89	70.11
EMS15	1	111	1.73	35.64	64.36
EMS16	2	90	1.40	28.00	72.00
EMS17	2	152	2.37	13.77	86.23
EMS18	2	246	3.83	44.39	55.61
EMS19	1	276	4.30	10.15	89.85
EMS20	3	208	3.24	36.31	63.69
EMS21	2	298	4.64	27.80	72.20
EMS22	2	158	2.46	32.58	67.42
EMS23	1	137	2.13	30.77	69.23
EMS24	2	89	1.39	31.71	68.29
EMS25	3	180	2.80	29.75	70.25
EMS26	2	84	1.31	30.38	69.62
EMS27	1	16	0.25	36.36	63.64
EMS28	2	214	3.33	37.43	62.57
EMS29	2	130	2.03	33.04	66.96
EMS30	1	29	0.45	30.43	69.57
EMS31	2	206	3.21	21.02	78.98
EMS32	2	173	2.69	32.47	67.53
EMS33	3	304	4.74	37.04	62.96
EMS34	2	487	7.58	18.50	81.50
EMS35	2	270	4.20	7.66	92.34
EMS36	1	79	1.23	38.03	61.97
Total	67	6421	100		
Average	1.86	178.36	2.78	28.67	71.33

NOTE. An ambulance rescue team consists of one ambulance staffed with one rescue team of 2 EMTs.



**TABLE 2.** Ambulance Rescue Team Utilization Rates for EMS Subgroups among Different Alternatives

Subgroups (Rescue Units)	% of Idle Errands* (IE)	Ambulance Rescue Team Utilization Rates (%)				
		Empirical Data		Computer-Simulated Data		
		Current Equipped Ambulance Level†	Lower Equipped Ambulance Level‡	Lower Idle Errand Rate by 10%§ [IE-(IE × 0.1)]	Lower Idle Errand Rate by 20%   [IE-(IE × 0.2)]	Lower Idle Errand Rate by 30%¶ [IE-(IE × 0.3)]
EMS1	31.74	10	19	20	20	20
EMS2	34.38	5	10	12	10	11
EMS3	33.85	6	6	6	6	6
EMS4	21.25	3	4	3	3	4
EMS5	28.95	15	15	15	15	16
EMS6	28.36	13	26	26	26	27
EMS7	16.10	5	10	10	10	10
EMS8	27.85	17	35	35	36	36
EMS9	17.27	4	11	10	11	11
EMS10	32.76	16	17	17	17	17
EMS11	25.66	6	11	12	11	12
EMS12	30.95	14	27	27	28	28
EMS13	29.86	2	7	7	7	8
EMS14	29.89	4	8	8	9	8
EMS15	35.64	7	7	7	7	7
EMS16	28.00	6	13	13	13	13
EMS17	13.77	11	22	22	22	22
EMS18	44.39	10	22	23	22	24
EMS19	10.15	20	20	20	20	20
EMS20	36.31	8	28	28	26	28
EMS21	27.80	6	13	13	13	13
EMS22	32.58	6	11	12	12	12
EMS23	30.77	7	7	7	7	7
EMS24	31.71	6	12	12	13	12
EMS25	29.75	2	6	6	7	7
EMS26	30.38	1	1	1	1	1
EMS27	36.36	28	28	28	28	28
EMS28	37.43	3	6	6	6	7
EMS29	33.04	7	12	14	13	15
EMS30	30.43	3	3	3	3	3
EMS31	21.02	8	16	15	16	16
EMS32	32.47	6	13	13	13	14
EMS33	37.04	8	30	27	28	31
EMS34	18.50	23	48	52	49	48
EMS35	7.66	12	24	24	25	25
EMS36	38.03	8	9	9	9	9
Average	28.67	8.78	15.47	15.64	15.61	16.00

NOTE. The percent of utilization rate equals the percent of time the ambulance rescue teams are used for go-errands (true plus idle errands) instead of sitting inactive. For example, the average utilization rate of 8.78% for the current situation indicates that 91.22% of the time ambulance rescue teams are ready to go for 24 hours a day but sit idle, waiting for the next rescue call to come in. An ambulance rescue team consists of one ambulance staffed with one team of two Emergency Medical Technicians.

\*Idle errand: ambulance departure from the subgroup and return to the subgroup without fulfilling a rescue, ie, false alarm.

†Current situation: the number of staffed ambulances per subgroup ranges from 1 to 3.

‡Staffed ambulance level has been reduced to 1 per subgroup.

§Staffed ambulance level has been reduced to 1 per subgroup, as above, and the idle errand rate has been set lower by 10%.

||Staffed ambulance level has been reduced to 1 per subgroup, as above, and the idle errand rate has been set lower by 20%.

¶Staffed ambulance level has been reduced to 1 per subgroup, as above, and the idle errand rate has been set lower by 30%.

trauma patients was significantly different than for non-trauma patients ( $P < 0.05$ ). Thus, these time distributions were managed separately.

The developed simulation model is shown in Fig 2. The rescue pattern for each individual response unit is displayed in Fig 3. Among the times for each step of the rescue, there are no significant differences ( $P > 0.05$ ) between the empirical data and simulated ones. The average of each simulated turnaround time is 37.72 minutes

(standard deviation, 0.59 minutes), which is close to 37.75 minutes (standard deviation, 1.33 minutes) of empirical data. Based on the current number of staffed ambulances per response unit, the average utilization rate of each response unit was 8.78% (Table 2). The average time interval between 2 rescue calls for the headquarters was 6 minutes. The possibility of 2 sequential rescue calls being reported simultaneously to the same response unit was only 8.1%. However, the situation for an event

**TABLE 3.** Time Performance Indicators of Ambulance Rescue Teams for Current Situation and among Multiple Alternatives

	Time Required to Arrive at Rescue Event Site (min)		Time Required to Arrive at Hospital (min)					
			(All Patients)		(DOA Patients)*		(Non-DOA Patients)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Current situation†	6.00	0.09	20.89	0.22	23.63	1.05	20.84	0.22
Computer Simulation								
Lower equipped level‡	6.27	0.12	21.12	0.20	23.86	1.14	21.07	0.20
Lower idle errand rate by 10%§	6.25	0.10	21.14	0.30	23.74	1.17	21.09	0.31
Lower idle errand rate by 20%	6.29	0.11	21.16	0.24	23.40	1.23	21.12	0.25
Lower idle errand rate by 30%¶	6.27	0.11	21.08	0.27	23.53	1.06	21.04	0.27
<i>F</i> Value of 1-way analysis of variance test	.53		.99		.56		.39	
<i>P</i> Value	.66#		.40#		.64#		.76#	

NOTE. An ambulance rescue team consists of one ambulance staffed with one rescue team of 2 Emergency Medical Technicians. Abbreviation: DOA, dead on arrival.

\*DOA = patients found to be in prehospital cardiac arrest.

†Current situation: The number of staffed ambulances per subgroup ranges from 1 to 3.

‡Staffed ambulance level has been reduced to 1 per subgroup.

§Staffed ambulance level has been reduced to 1 per subgroup, as above, and the idle errand rate has been set lower by 10%.

||Staffed ambulance level has been reduced to 1 per subgroup, as above, and the idle errand rate has been set lower by 20%.

¶Staffed ambulance level has been reduced to 1 per subgroup, as above, and the idle errand rate has been set lower by 30%.

#There is no significant difference under a level 0.05.

with no ambulance available for rescue (an invalid call) never occurred during the simulation time period.

If the levels of available ambulances staffed with EMTs are reduced from the present 1 to 3 ambulances per response unit to 1 (called lower equipped level), the average utilization rate will increase from 8.78% to 15.47% for each staffed ambulance (see Table 2). Under those conditions (as shown in Table 3), the average times required for ambulance arrival at the incident site ( $6.27 \pm 0.12$  minutes) and arrival at the hospital ( $21.12 \pm 0.20$  minutes) are slightly longer than the ones of the current equipped level (current situation) ( $6.00 \pm 0.09$  minutes and  $20.89 \pm 0.22$  minutes, respectively). However, there is no statistical delay in ambulance arrival at the scene for patients after the ambulance level was decreased. No invalid calls in the form of having no ambulance available for rescue occurred in the entire simulation time, whether under the existing, current situation reported rate or under the scenario of reduced ambulance and team staffing to 1 per response unit (lower equipped level). Therefore, we conclude that with fewer ambulances and rescue team staff, the cost can be reduced and the utilization rate and the performance in the given event report rate can be improved. Based on the results of this research, we determined that the subject EMS system has a high idle errand rate (28.67%) (see Table 1). The simulation predicts the possible outcome when the number of ambulances per EMS subgroup is reduced to 1, and the idle errand rate is reduced by 10%, 20%, and 30%. By performing analysis of variance tests across multiple alternatives, we found that there were no significant differences in the time intervals from ambulance arrival at the scene and arrival at the hospital, although the utilization rate of ambulances rises (see Tables 2 and 3). Under the current event report rate, no calls occurred during the simulation that resulted in having no ambulance available for rescue. We

conclude that even if the number of ambulances is decreased, one can still try to reduce the idle errand rate make the rescue teams and ambulances more effective and efficient.

The outcome of patients for the prehospital rescue model is affected by an important factor—the time required for providing the emergency care at the scene and definite care in the hospital emergency department. Under the current EMS model, the time spent to transport patients to a hospital was 20.89 minutes for all patients and 23.63 minutes for prehospital cardiac arrest patients. The average time taken for a rescue team to arrive at scene was 6.0 minutes for all patients. After we changed the number of ambulances, the average time taken for a rescue team's arrival at scene was 6.27 minutes; the mean time spent to transport patients to a hospital was 21.12 minutes for all patients and 23.86 minutes for prehospital cardiac arrest patients. For prehospital cardiac arrest patients, there is no statistical difference among the times required to reach the hospital under the 2 scenarios. The same result can be found between other alternatives (see Table 3). Therefore, we conclude that the care delivered to patients will not be delayed even though the number of ambulances and the idle errand rate have both been changed (see Table 3).

## DISCUSSION AND CONCLUSION

Simulation is generally defined as “the imitation of the operation of a real-world process or system over time.”<sup>14</sup> “Simulation involves the generation of an artificial history of the system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented.”<sup>14</sup> Simulation is used to describe and analyze the behavior of a system, ask what-if questions about the real system, and aid in the design of real

systems. In management science, simulation is a problem-solving methodology for the solution of many real-world problems.

There are various kinds of simulation models, and their ramifications are complex.<sup>14</sup> Dynamic system models generally can be classified into 3 groups: symbolic models, analytic models, and simulated models.<sup>14,15</sup> Among those, the simulated model is a tool of performance assessment, generally using computer software to simulate a system's behavior, explore real-world causal relationships, and assess the system's performance in terms of resource utilization rate, turn-around time, waiting time, and so on. In addition, it can be used to predict possible outcomes for the system after changing some manipulable conditions. By simulating various alternatives and predicting their corresponding results, a conclusion can be provided for decision makers' reference.

Many fields use simulation methods to resolve problems in complicated systems such as military simulations, including war strategy simulation, arms and troop distribution simulation, logistics transportation simulation, and communication simulation.<sup>15</sup> Service systems' simulation includes process reengineering simulation, on-line simulation, and resource management simulation. Distribution systems' simulation covers manufacturing process simulation, performance evaluation simulation, and cycle-time simulation, among others. The medical care systems' simulation covers the range of total quality management or continuous quality improvement and resource management simulation.<sup>16-20</sup> The previously mentioned applications all attempt to use simulation techniques for real-world operations and management.

The advanced computer simulation software was applied in our research to remodel the subjective EMS system. To mimic the real performance of the system, the following empirical data are essential to establish the simulated model, including frequency of incident happening, time required in every activity of EMS operation, amount of resources, and final destination. By simulating changes in resource allocation, performance of the EMS system can be expected to improve. In summary, the conclusions are as follows: (1) the utilization rates of EMT personnel and ambulances of the subject system are presently low; therefore, the number of staffed ambulances can be reduced to increase the utilization rate while maintaining the current rules of operation and (2) decreasing the number of staffed ambulances would not noticeably increase patients' rescue waiting time (less than 1 minute increase on average) or produce idle calls because of ambulance nonavailability.

Therefore, according to the results of our research, we suggest that EMTs and ambulances of every response unit be reduced to 1 team with 1 ambulance in a subjective EMS system to reduce costs and increase efficiency while maintaining the same operational pattern of medical service.

However, we also find that for the prehospital cardiac arrest patients, around 24 minutes are usually required to transport them to the hospital, whereas it takes only about 6 more minutes for EMTs to arrive at the scene. The literature review indicates that the prognosis for prehospital cardiac arrest patients was determined by the use of basic lifesaving

and advanced lifesaving techniques, and the best time for that intervention is within 8 minutes of the incident.<sup>1,2,21-24</sup> Therefore, if medical personnel or advanced lifesaving personnel can perform rescues earlier at the scene, would the patient survival rate be elevated? This deserves further research attention.

This study provides a research methodology and suggestions toward specific policy directions, although the study is constrained by its database. In view of limited observation information in our research, the seasonal or monthly impacts cannot be integrated, and the amount of services is assumed to be the same as for previous patterns. Hopefully, future research may address these limitations and impacts and provide service projections based on empirical data covering longer periods of time.

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