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SIMULATION MODEL OF THE TELEMEDICINE PROGRAM

J. Mauricio Lach
Ricardo M. Vázquez

Av. Lomas Anáhuac s/n, Lomas Anáhuac
Universidad Anáhuac
Huixquilucan, Edo. Méx. 52760, MEXICO

ABSTRACT

The Telemedicine Program was created to provide medical assistance to people living in extreme poverty conditions in Mexico. Through a satellite connection, a physician located in Mexico City can diagnose the patient who is physically inspected on a mobile unit, equipped with telecommunications gear. The program's performance has brought positive results, and is starting to expand to farther regions. This paper explains how the program's processes were simulated on a specially designed logical-mathematical computer model in order to observe, and analyze the possible results generated when specific information of the model's parameters is introduced. The results shown by the model when different scenarios are being run, can be used as a powerful tool in the decision making process in order to optimize the program's performance by maximizing its utilization and efficiency, looking forward to incrementing its productivity.

1 OPERATION OF THE TELEMEDICINE PROGRAM

The program has its central operating base in Mexico City in the Faculty of Medicine in Universidad Anáhuac. A second base point is installed in CIDECO (Integral Community Development Center) Acapulco, in the state of Guerrero.

The mobile unit's staff is conformed by 2 persons: a physician passant, and a technician, both of them instructed in the usage of the unit's gear and medical equipment. The Telemedicine program considers that the passant, as well as the technician, are subject to a primal learning curve at the beginning of their participation on the program. This curve should last no longer than three months under a full time working basis.

The Telemedicine Program's patient-attending system is conformed by three stages: first filter, second filter, and tele-consult stage. The number of patients attended in the first filter corresponds to 80% of the population in need of special medical assistance. The second filter treats 15% of the total, and the tele-consult stage receives 5% of them.

This information is validated by the Worldwide Health Organization's statistical database. These studies present a global tend in which only 5% of the patients have access to a third level (health) institution (each level represents an increment in the quality and degree of medical specialization of the institution); 15% of them are treated on a second level institution, and 80% of the patients are received by a first level institution.

1.1 Operation's Service Mechanics

1.1.1 Deciding the Community

The program is applied to a whole region previously studied on a basis of poverty conditions. The first region chosen corresponds to Costa Chica, Guerrero.

Once the region is selected, the cities and towns have to be analyzed in order to choose those with greater poverty problems. The interest and acceptance of the local authorities on applying the program is verified. It is also taken into account that the conditions of the roads leading to the communities satisfy the minimum physical requirements that enable the unit's access to the area.

1.2 Filter 1

Objective: Determine which local patients are in need of a tele-consult with the medical specialties offered by the Telemedicine Program.

Local medical authorities examine the patients. Tele Medicine program lists contain the patients who can not be treated by local medical authorities, and are in need of deeper medical analysis.

1.3 Filter 2

Objective: Determine if the patients programmed in the tele-consult lists require the attention of a specialized doctor.

In this filter, the physician passant begins to receive the patients, previously scheduled by the local medical authorities. Once with the patient, the passant conducts a brief dialogue with him in order to either prescribe him treatment, or send the patient to see a specialized doctor through the tele-consult. The ambulance presence in the community is required in order for this stage to take place.

1.4 Tele-Consult

Objective: To offer a medical service capable of satisfying the patient's health needs that cannot be solved by the local physicians, or in filter 2.

There are 3 basic requirements, in order for the tele-consult to take place:

- the ambulance has to be in the community
- the satellite connection between the ambulance and the central operating base has to be activated
- the specialized doctor has to be at the central operating base

Once the patient has been attended, the specialized doctor determines if the patient must be sent to a specific medical institution for further analysis, or if by prescribing him treatment should be enough.

2 PROBLEM

The Telemedicine Program is relatively new (started in August, 2002). Due to this situation, the working procedures haven't been previously planned, so they mainly have been developed as the program has been taking place. The common sense and program's authorities way of thinking have been the main criteria in the decision making process. These managing conditions have generated working methodologies capable of getting the work done, but are susceptible of changes in seek of a more efficient and productive way of performing work.

The resources that make possible the program's operation haven't yet been exploited until their tolerable limits are being reached. The logistical aspects of the program haven't been studied with the required priority in order to minimize operational costs. It has been difficult to achieve an efficient programming of the doctors' schedule, as well as managing and utilizing the program's resources and personnel under a maximum capacity scheme. The frequency of the tours and the routes taken need to be rethought; efficiency must be incremented in the resource optimization and working capacity aspects so that the program's actual geographical coverage can be expanded. A mathematical tool is needed to assist the program's authorities in the decision making process.

3 METHODOLOGY OF THE SOLUTION

A logical - mathematical model that represents the actual operation of the Telemedicine Program applied in the region of Costa Chica, Guerrero was developed. This discrete-event model is flexible enough so it can be used as a powerful choice making tool, in order to predict future results under several scenarios varying each from one another, depending on the values given to the following system variables:

3.1 Incoming Times

- number of patients per population of visited community
- patients characteristics
- percentage of patients in need of a second or future inter-consult

3.2 Service:

- tour programming
- unit installing time
- connection installing time
- connection's time length
- number of medics
- service times:
  - filter 1's consult time length
  - filter 2's consult time length
  - tele-consult's time length
- physicians' specialties
- physicians' schedule

The social and demographical characteristics of the region are being introduced as an external factor so that the model can be implanted in a different region to forecast the program's behavior in that specific place.

The program's information needed to construct the model was gathered from two main sources: the first one constitutes the information supplied by the telemedicine's database; the second source of information was our own data gathering process, consisting of personally attending a tour along the telemedicine's staff in the ambulance in order to observe their exact working procedures as well as measuring and registering the information generated by their activities.

4 DATA ANALYSIS AND MODEL CONSTRUCTION

To ensure the model's flexibility, the following parameters were established; by using them, the model's variables information can be altered, in order to adapt it to the different conditions that could be presented by the region where the program is applied.

4.1 Parameters

4.1.1 p_d1

This parameter considers the number of physicians available of specialty 1 in the central operating base in Universidad Anáhuac. Another five parameters like this one were created to represent the six medical specialties with which the Telemedicine program counts.

4.1.2 p_comsize1; p_ comsize2;, p_ comsize3; p_comsize4

These parameters consider the size of the community to be visited and are determined by a normal distribution N(200,50). Their values can be modified in order to adapt the model to specific demographic conditions. Four communities were considered as an initial number in the model due to the general number of communities that the Telemedicine Program plans in a standard tour. However, the number can be modified.

4.1.3 p_numbofcommunities

This parameter considers the number of communities that will be visited on the tour.

4.2 Time Distributions

The probabilistic distributions chosen to simulate the time length's in each activity were obtained as a product of statistical analysis. This study determined which probabilistic distribution fitted and adjusted the best in relation with the time ranges acquired. To find these distributions the software program Stat Fit was used.

It can be seen that in all three of the following cases, that the probabilistic distributions behaved in an exponential way. The inter-arrival times have also an exponential distribution behavior, corresponding to a Poisson distribution arriving rate.

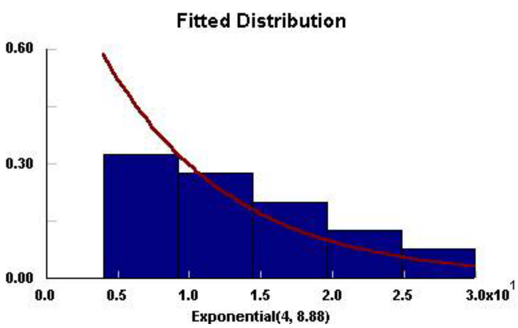

Figure 1: Time Distribution of FILTER 1

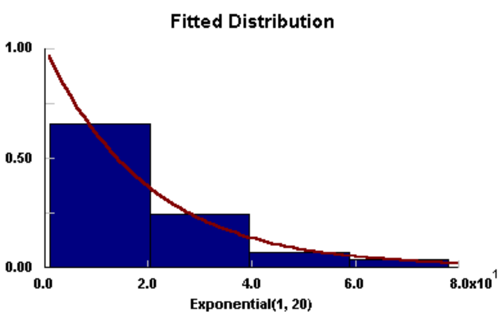

Figure 2: Time Distribution of FILTER 2

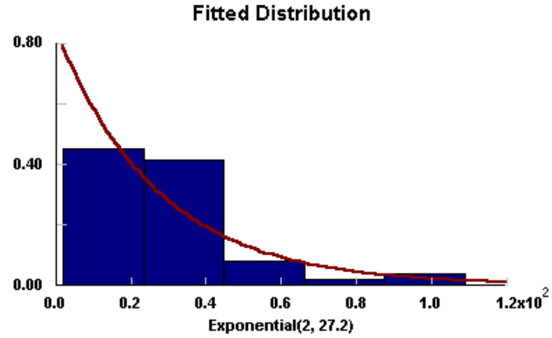

Figure 3: Time Distribution of the TELE-CONSULT

4.3 Model

The model constructed (using Process Model) is visualized by the following 2 main diagrams:

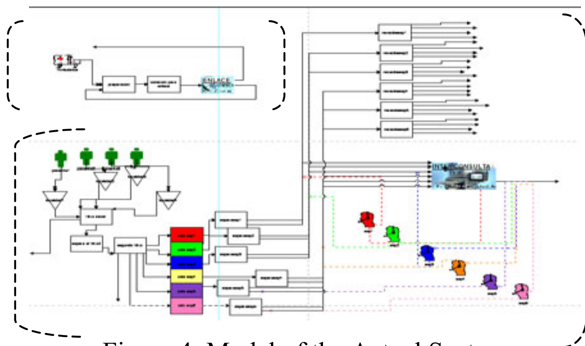

Figure 4: Model of the Actual System

The smaller diagram consists on the route taken by the ambulance, as well as the different procedures that need to take place in order to establish the satellite's link between the mobile unit and the central operating station. The larger diagram represents the telemedicine's program patient attending system. In order for the filter 1 and tele-consult sections to begin working, it is necessary that the ambulance in the smaller diagram (Figure 5) reaches the satellite's link stage. The model considers as a starting point the base installed in CIDECO Acapulco, Guerrero.

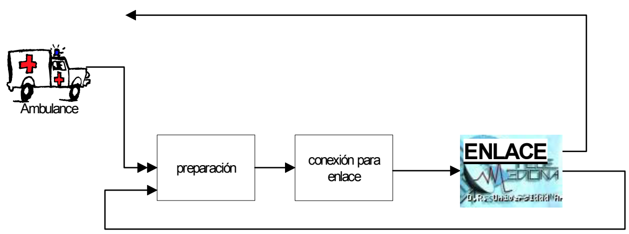

Figure 5: Mobile Unit's Route

The duration considered for the simulation, in relation with the series of events that need to be followed in order to get the unit prepared for the satellite's connection, is 120 minutes. The time length needed to establish the satellite's link has an exponential behavior, as it can be seen in Eq. (1).

$$\text{Connection time length} = e\,(15)\text{ min} \qquad (1)$$

The link dialogue box considers a continuous satellite connection of 18 hours; this range refers to the time length that the mobile unit spends in one community. All these values can be modified if desired, directly in to the model in the diagram boxes that appear in Figure 5.

Once the preparation step (first box in Figure 5) is carried out, the variable V_link is modified; a unit is added to its initial value. This situation makes possible the flowing of patients from filter 2 into the tele-consult stage.

Example

Text in the action box of a medical specialty tele-consult queue, representing this situation:

```
Inc V_sp1typediatrics
If V_link1=0
Then Wait Until V_link1=1
```

Once the communities have been visited, the ambulance returns to the CIDECO base point. This determines the end of the tour.

The following section of the model represents the patients' arrival, as well as the different processes that make possible the medical attention provided by the system. The next figure shows the simulation of how the patients from four different communities are attended under the different telemedicine system filters until their arrival to the tele-consult phase.

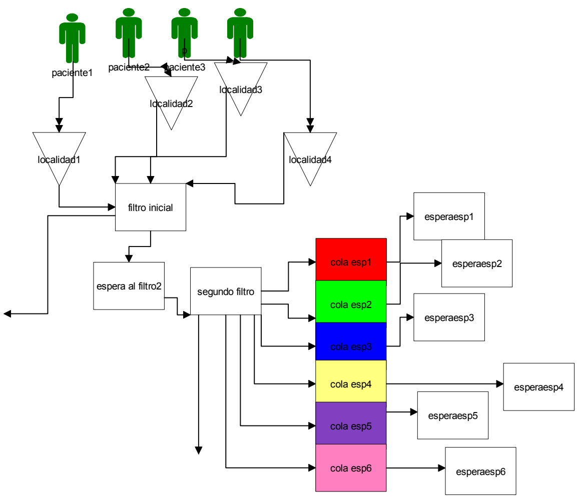

Figure 6: Filter 1, Filter 2, and Queuing Section

Besides the satellite's link, the doctor's presence in the central operating base is crucial for the tele-consult phase to take place. The actual schedule of the Telemedicine Program with which the shifts were introduced to the model is represented in Table 1.

Table 1: Doctors' Shifts

TIME	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
07:00					
08:00					
09:00	Pediatrics		Pediatrics		Pediatrics
10:00		Gynecology			
11:00			Pediatrics	Gastroenterology	Pediatrics
12:00			Nutrtition		Nutrtition
13:00					
14:00					Gastroenterology
15:00					
16:00		Surgery			
17:00			Adult	Adult	
18:00			Nutrtition	Nutrtition	

It is important to mention that sometimes the specialist does not arrive to its appointment. When this occurs, one of the doctors in charge of the Telemedicine's program takes the place of the specialty doctor. We have called this situation with the name "Extra Physician".

5 VERIFICATION AND VALIDATION

The following graphics were generated to validate the correct execution of the model.

The patients' arrival follows a random order. The probabilistic distribution in this stage corresponds to a normal distribution: N (200, 50). This behavior can be seen in Figure 7.

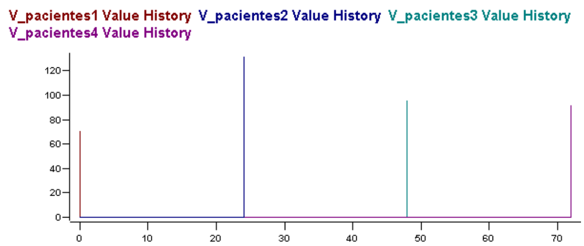

Figure 7: Patients' Arrival to Each Community

The following Figure (8), represents the random percentage of patients' arrival and determines the number of patients that will take part in the tele-consult process. The four graphic steps that can be seen in each of the figure's tend lines, respectively represent the number of patients that have taken part in each of the 3 steps of the tele-consult process (filter 1 – filter 2 – tele-consult) in the four communities visited during the tour.

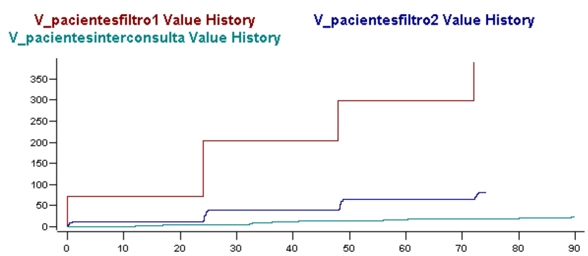

Figure 8: Quantity of Patients in Each Step of the Tele-Consult Process.

Figure 9 exhibits the mobile unit's satellite connection link with the central operating base, as well as its time length. With this tool the utilization's percentage of the satellite's connection can be determined on a monthly basis.

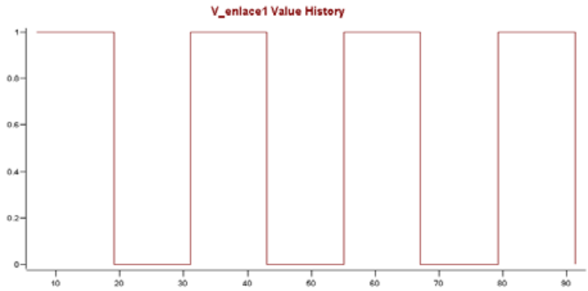

Figure 9: Connection Link

First a model was constructed using only 3 specialized or category physicians to verify its performance. On the next model, another 3 medical specialties were added.

The number of patients that are in need of medical assistance in each of the 3 medical specialties per community, can be seen in Figure 10.

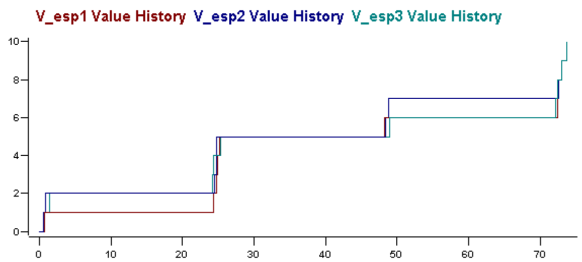

Figure 10: Patients in Need of Each of the Medical Specialties

The model was run several times in order to achieve its stability. By the tenth run (ten tours) it was clear that the risk of obtaining temporary results due to simulating a transitory state of the program's performance was overcome. Each run simulates the program's working performance of 7 days.

In order to validate the model against the actual situation, the results obtained by simulating were compared against the data collected of the program tours. In relation with the quantity of patients treated, there was a huge similitude between the numbers generated by the model and the actual number of patients that had been attended during the tours.

The Telemedicine Program's data files were the main source of information in order to validate the model results. As a second information source we personally attended to two of the field tours and collected all the data that could tell us mainly the following things: if the model results could be true, as well as if the previously obtained data by the program's staff could be appreciated with the proper certainty. After the proper analysis, we concluded that the information collected by the program's staff was truthful.

6 SOLUTION

The model created simulates the optimal (all specialists arrive to their appointments) actual situation of the Telemedicine Program. Its added value lies on its ability for simulating different realities, in order to see the difference(s) in the results, when a modification in the program's working procedures presents; the next step consists on verifying the possibilities of the system to be improved.

Simulating with the model must be done by the Telemedicine authorities. Because of this reason, the model was created keeping it as flexible as possible, and was constructed in such a way, that any person without any modeling or Process Model – programming skills, could be able to experiment with it without any troubleshooting.

As a first variation of the actual situation, the "Extra Physician" scenario was simulated. This modification on the model consists on adding a generic physician that acts as a wildcard whenever any of the specialized physicians isn't able to attend a tele-consult. A comparison between the quantity of patients attended by running the actual situation scenario and the extra physician scenario is presented in Table 2.

Table 2: Comparison between Results

	Extra Physician Scenario	**Actual Situation Scenario**
Medical Specialty	*Patients Treated*	
General	626.2 ± 109.7	401.2 ± 75.85
General2	111.5 ± 19.72	79.9 ± 16.19
Pediatrics	5.2 ± 2.14	2.4 ± 1.5
Gynecology	6 ± 2.21	2.3 ± 1.33
Pediatrics Nutrition	7.4 ± 2.06	2.7 ± 1.7
Gastroenterology	6 ± 2.10	0
Surgery	6.2 ± 1.54	0
Adults Nutrition	7.7 ± 2.58	0

The results shown above are part of the results list of the ENTITY SUMMARY; however, the tendency presented by the comparison is maintained for the rest of entities.

- General: total number of patiens attended (including those who only were part of filter 1).
- General 2: patients attended in filter 2.

7 CONCLUSION

By running the actual situation model, the percentage of utilization of the tele-consult is 1.44%, while adding an extra doctor to the model, provides a tele-consult utilization of a 28%. By comparing these results, it can be seen that the usage percentage dramatically increases when an extra physician is in the picture. With this variation, more patients are treated. The principal reason of the low utilization percentage of the actual situation scenario, can be explained as an inefficient programming of the physicians schedule.

It is important to note that sometimes, the telemedicine program's system works like the "extra physician" scenario, eventhough there isn't a general awareness of it.

The number of patients who leave the system without having had a tele-consult is cero. The actual demand on the service provided by the Telemedicine Program is not as high as what was expected. On the other hand, a lack of people in need of medical assistance in rural regions of Mexico does not reflect the reality. The principal causes of the system's actual inefficiency are:

- Ineffective specialty doctors schedule programming,
- Miscommunication between the Telemedicine Program and the local medical authorities; and basically,
- Local community doctors do not inform about the Telemedicine's program tours with enough anticipation in order for the patients to know when to attend the local health center.

The system's capacity has still a wide range for growing. Many different scenarios can be developed in order for the Telemedicine's Program to apply the specific modifications that would optimize its service capabilities. Utilizing two parallel mobile units, extending the width of the satellite's link range, or increasing the number of specialized doctors are just part of the series of possible combinations that can be valued through the model in order to increase its productivity, and keep on bringing positive results to the community.

As it is planned, the program will be extended in a near future to the states of Oaxaca, Michoacan, and Yucatán. For each of this new regions, more staff and mobile units will be needed, as well as regional operational centers with more physicians' schedules to program, and satellite connection links to be established. The operational and logistical planning plays a key role in keeping the program's performance effective, in having a strong infrastructure that can support the expansion plans of the program, and in being able to provide quality medical assistance to those people without the posibilities to access to it.

AUTHOR BIOGRAPHIES

MAURICIO LACH was born on February 6, 1980 in Mexico City. He started college studies at Universidad Anáhuac in Mexico City in August, 2000. He is currently coursing the last year of his B.S., majoring in Industrial Engineering and minoring in Systems and Production. During the past three and a half years in college, he has received three academic merit awards and a scholarship due to academic excellence. He has also been selected to participate in the national interdisciplinary (academics-government-private investment) congress, "Espacio Vanguardia 2003". His e-mail address is <mauricio_lach@yahoo.com.mx>.

RICARDO VAZQUEZ was born on October 22, 1981 in Mexico City. He started college studies at Anahuac University in the State of Mexico in the year 2000. At this moment he is finishing his last year of college with a major in Industrial Engineering and a minor in Systems and Production. He has been awarded a full scholarship due to academic excellence, as well as four merit awards. During the past six years, he has been dedicated to community service in the field of education in mathematics regularization and alphabetization. His e-mail address is <ricardomvh@prodigy.net.mx>.