

# A Machine Learning Approach for Telemedicine Governance

Telemedicine is a component of ehealth that uses information and communication technology (ICT) to deliver health care services to overcome distance and connect the provider and the patient. “Telehealth isn’t just about the patient and treatment, but knowledge about the equipment is vital as well.”<sup>1</sup>

Telemedicine helps during teleconsultation and tele-education for local doctors by facilitating efficient delivery of medical care to “remote areas, vulnerable groups and aging populations.”<sup>2</sup> Telemedicine also helps to provide postoperative care through remote follow-up and monitoring.<sup>3, 4</sup> An efficient telemedicine initiative requires an active ecosystem that is comprised of patients, care providers, information technology and participating hospitals within the network. Proactive telemedicine governance helps to ensure an efficient health care delivery system and improves the quality of experience.<sup>5</sup>

This article presents a two-stage decision support system (DSS) framework for telemedicine governance, known as the DSO-R model. The first stage is the department-session-organization (DSO) model, which uses a machine learning approach to predict the probability that a remote organization will participate in a particular telemedicine session; the second stage is the risk estimating (R) model.

Budget constraints and poor demand for telemedicine in lower- to middle-income countries make optimal usage of available resources necessary. A case study of the TELEMED medical center in India is used to validate the model.

## Barriers to Telemedicine

The telemedicine market is growing globally at a compounded annual growth rate (CAGR) of 14.3 percent and, from 2014 to 2020, is expected to reach US \$36.3 billion. Teleconsultations are among the most common type of telemedicine sessions.<sup>6</sup> Despite the rising demand for telemedicine, research attributes the low penetration of telemedicine to (figure 1):

- Initial setup cost
- Competition for care delivery systems
- Lack of technical knowledge
- Concern for health care standards<sup>7, 8</sup>

Telemedicine has some initial setup and running costs that need to be covered by the revenue obtained from telemedicine sessions. Thus, an optimal number of sessions ensures the sustainability of the project.<sup>9</sup>

## Applying the DSO-R Model

Telemedicine sessions that are related to diabetes, intensive care units or hemodialysis use machine learning techniques in a clinical decision support system (CDSS).<sup>10, 11, 12</sup> The purpose of the DSO-R model is to understand the objectives of health care organizations for setting up a telemedicine project and their traditional health care delivery processes and to determine the health care organizations that are best suited to set up telemedicine session initiatives. One can manually compute the expected loss of the organization conducting the telemedicine

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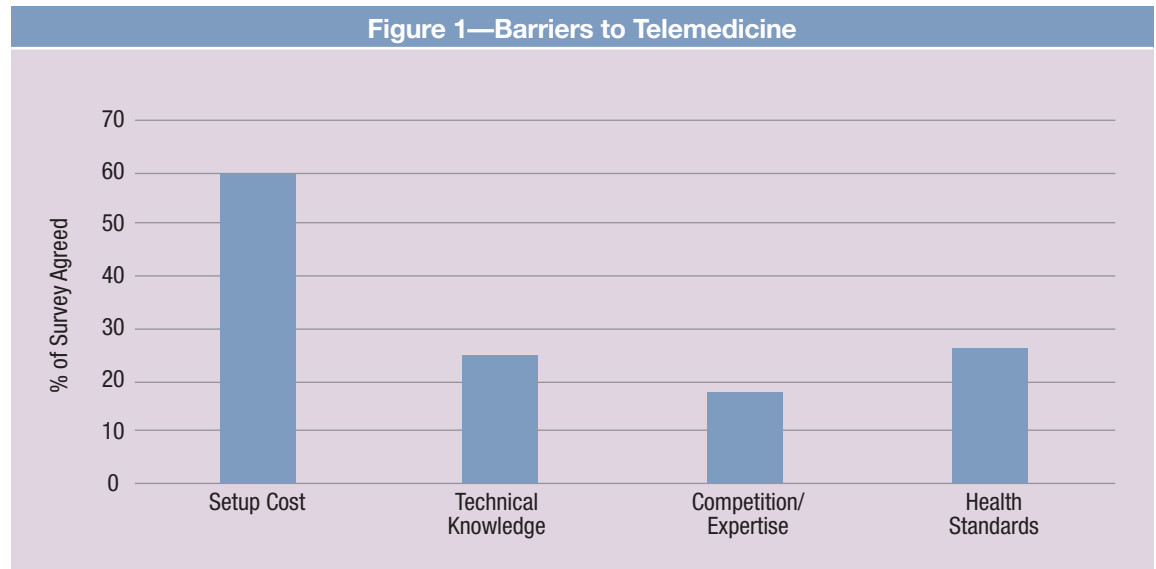


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session, in case the model incorrectly selects a remote hospital through its classification mechanism based on the following input parameters:

- Department type (i.e., endocrine surgery, transfusion medicine)
- Session type (i.e., general sessions, follow-up, tele-common grant round [tele-CGR])
- Receiver organization type (academic or nonacademic)

After learning from prior knowledge, the telemedicine DSO model predicts the partner health care organizations (e.g., National Medical College Network [NMCN], South-East Asia Telemedicine Forum and Sub-Sahara e-Network Project) that are best suited for setting up a telemedicine session initiative. Such a model can help to optimize TELEMED's reach across India and abroad.

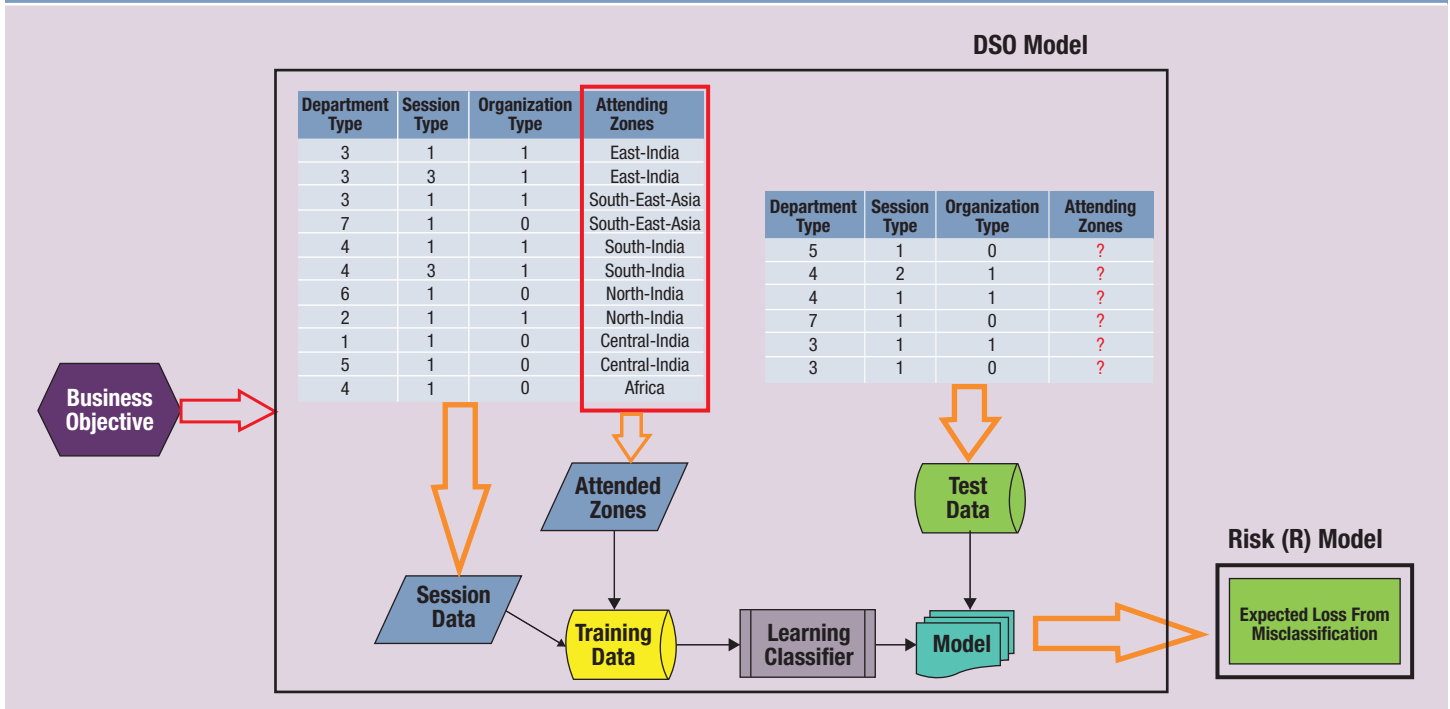
The risk-estimating model computes the expected loss arising from misclassification in the DSO model prediction of suitable partner health care organizations. The risk computation depends on the accuracy rate of the decision tree, interest of patients in telemedicine, in-house treatment available and monetary impact of an admitted patient. **Figure 2** illustrates the proposed DSO-R model.

## Telemedicine In India

Associated Chambers of Commerce and Industry of India (Assocham) reported a 20 percent annual growth rate of the telemedicine market in India and estimated that its market value will double by 2020, to US \$32 million.<sup>13</sup> Telemedicine service delivery is ideal for India, because it has vast expanses of remote hilly regions, tribal areas and islands,<sup>14</sup> in which "Seventy-five percent of the doctors practice in urban, 23 percent in semi-urban areas and only 2 percent in the rural areas where the vast majority of the population lives."<sup>15</sup>

Telemedicine projects at the Christian Medical College (CMC) Vellore and All India Institute of Medical Science (AIIMS) New Delhi are set up in collaboration with the Japanese International Cooperation Agency (JICA). JICA provided the initial investment for the IT equipment for telemedicine initiatives. The 11<sup>th</sup> five-year plan of the Government of India, for 2007-2012, lists 11 states (including Andaman-Nicobar and Lakshadweep) and eight super-specialty hospital networks that have established telemedicine projects.<sup>16</sup> The type of communication used is video satellite (VSAT or Sky IP), integrated services digital network (ISDN) or both. The funding and implementing agencies of the different telemedicine projects are carried out by

Figure 2—Telemedicine DSO-R Model



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Indian Space Research Organisation (ISRO), Centre for Development of Advanced Computing (CDAC), IIT Kharagpur and others. The Department of IT, Ministry of Information and Technology of India is also acting as the facilitator for several telemedicine projects.<sup>17</sup>

## Case Study

A case study of the TELEMED medical center is used to measure and validate the DSO-R model. The vision for TELEMED in Lucknow, India, was adopted from the US National Institutes of Health (NIH) Clinical Center:

*TELEMED intends to be a top-class medical institute in Asia, with the intention to minimize long distances traveled for treatment of their diseases. TELEMED also intends to emerge as a super-specialty medical care unit, in terms of availability of skilled doctors, nurses and technicians and being able to meet up to international best practices.*<sup>18</sup>

TELEMED is a tertiary-level referral academic medical center that is mainly involved in training and teaching in the 18 specialist departments in its 30-department center. The aim of the medical center includes delivering state-of-art tertiary-level medical care, and super-specialty research and capacity building through teaching and training.

TELEMED has moved toward maintaining a well-developed infrastructure for education, research, training and application for telemedicine. TELEMED receives both intramural and extramural project grants that have aided in the sustenance of the telemedicine program and research works. The funding institutions include several national and international funding agencies. TELEMED also conducted approximately 450 intramural projects that helped it to sustain its research incentives.<sup>19</sup>

TELEMED wanted to analyze its past data about departments that were involved in telemedicine sessions (general sessions, follow-up and tele-CGR) with remote organizations (academic or nonacademic). It was also necessary to determine

the risk that is associated with an incorrect decision made by the DSO-R model. Realization of the cost associated with the risk can help to optimize telemedicine session utility and minimize the loss.



## Methodology Used

This section describes the methodology that was used in the TELEMED case study.

### DSO Model

TELEMED's past data consist of various levels of categorical variables. This type of data set is ideal for developing classification rules that can contribute to the identification of the target from a given pattern of attributes.<sup>20</sup> The classification tree is implemented through the MATLAB R2012a program. The program predicts the location of the remote organization based on predictors entered by the user. The classification rule consists of the probability of occurrence of different zones for a particular set of data. The accuracy of the classification tree was tested by training the classification tree with 80 percent of the past data set and using the remaining 20 percent as a test set. This DSO model will help to reduce the low-utility risk that is associated with a telemedicine session.

### Risk (R) Model

The R model further determines the accuracy of the decision tree. A hospital incurs a considerable inpatient care cost (about 43 percent in the United States).<sup>21</sup> If a patient is not treated properly through a scheduled telemedicine session, then the cost to the patient and the hospital increases. An exponential function of number of days and diffusion rate of ICT was used to calculate the number of patients who used telemedicine (**figure 3**).

**Figure 3—Number of Patients Who Arrived for Telemedicine Treatment**

Number of patients who arrived at the telemedicine center for treatment =

$$\frac{\text{Population of the rural setup where the telemedicine center is located}}{1+e^{-bx}}$$

where b = diffusion rate of ICT and

x = number of days post introduction of telemedicine center at remote location.

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The result of the **figure 3** equation was used in the equation in **figure 4** to determine the expected loss for each day.

**Figure 4—Expected Loss per Day**

Expected loss per day = Population \* (1-Accuracy of location classifier) \* Number of patients who arrived at the telemedicine center for treatment \* {1-Probability (Treatment available)} \* Probability (Patient travels for further treatment) \* Monetary impact due to patient admission

where the "monetary impact due to patient admission" is denoted as a negative value

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### Data

The data on session details for each telemedicine session that the TELEMED telemedicine project group conducted from 2007 to 2015 consisted of 2,612 data points, which are categorized in **figure 5**. They consist of more than 30 departments and three session types, i.e., general sessions, follow-up sessions and tele-CGR sessions. Several partner health care organizations associated with TELEMED for teaching and patient care. The partner hospitals

were separated into teaching and nonteaching organization types. For simplicity of explanation, **figure 5** shows only the top seven departments (in maximum number of sessions) and categorizes the partners into six zones.

The purpose of the case study is to establish a pattern between location determination (zone) and session type to ensure error-free decision making. The results can also be used to recommend zones for conducting new sessions and can be included as a part of TELEMED's risk mitigation strategy.

## Results

### DSO Model

In the first stage of the DSO-R model, the resultant zones were determined based on their probability of occurrence for a predictor set. The resultant decision tree that is illustrated in **figure 6** can suggest only a single zone based on a particular set of predictors.

**Figure 7** compares the predicted data with test data for the test data set. Not all the predicted data match

the test target data. The prediction tree predicted 415 out of 523 (80 percent) of the test data set accurately. However, the receiver operating characteristic (ROC) curve performed better for S-E-A, South-India and East-India due to the higher number of sessions of these zones in telemedicine activities (**figure 8**). Central-India and North-India showed lower accuracy due to lack of consistency between training and test data. The prediction accuracy was highly affected by the prior knowledge of the training data set and, therefore, can be a weak recommendation system.

### Risk (R) Model

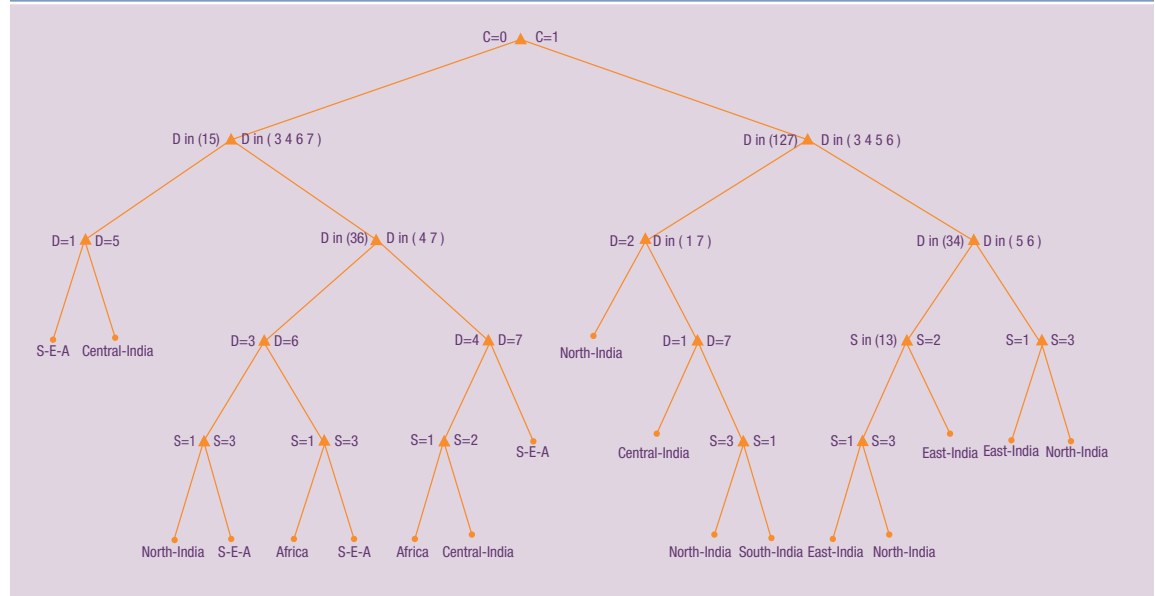
In the second stage of the DSO-R model, the equation in **figure 4** was used to calculate the expected loss due to misclassification of the decision tree in the first stage. In a rural setup in India with a population of 3,000, the pace of diffusion of ICT is slow (0.05). Therefore, the number of patients who arrived at the telemedicine center for treatment is a minuscule fraction of the rural population tree. For a public super-specialty hospital, it is always important to lower the cost. The accuracy rate of the decision is rounded off to 70

**Figure 5—Categorized Data Set for TELEMED**

Department types (D)	<ol style="list-style-type: none"> <li>1. Administrative activities</li> <li>2. Case-based teaching</li> <li>3. Clinical immunology</li> <li>4. Endocrine surgery</li> <li>5. Nursing skill</li> <li>6. Pathology</li> <li>7. Transfusion medicine</li> </ol>
Session types (S)	<ol style="list-style-type: none"> <li>1. General</li> <li>2. Follow-up</li> <li>3. Tele-CGR</li> </ol>
Organization types (C)	<ol style="list-style-type: none"> <li>1. Nonteaching hospital</li> <li>2. Teaching hospital</li> </ol>
TARGET: Zones	<ol style="list-style-type: none"> <li>1. Africa</li> <li>2. Southeast Asia (S-E-A)</li> <li>3. East India</li> <li>4. Central India</li> <li>5. South-India</li> <li>6. North-India</li> </ol>

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Figure 6—Classification Tree Using TELEMED Training Data Set



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Figure 7—Effectiveness of the Classifier on the Test Data Set

Department Type	Session Type	Organization Type	Predicted	Actual
5	1	0	Central-India	Central-India
4	2	1	East-India	East-India
4	1	1	East-India	North-India
7	1	0	South-East-Asia	South-East-Asia
3	1	1	East-India	South-India
3	1	0	Africa	Africa

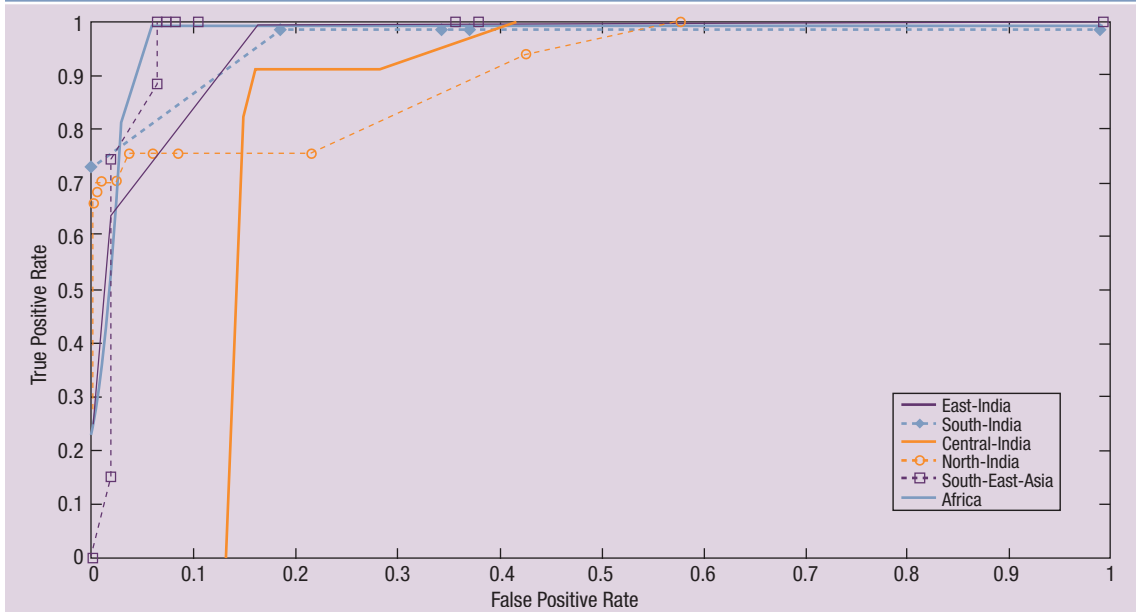
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percent. For the purpose of simulation, the equation in **figure 4** is used, where the probability (treatment available) equals 12 percent, probability (patient traveling for further treatment) equals 60 percent, and monetary impact equals US \$135. **Figure 9** demonstrates the result of the calculation and also computes the average expected loss for each day.

## Conclusion

The data and session details were analyzed carefully and then the data set was further simplified by selecting appropriate departments based on TELEMED's frequency of telemedicine broadcasting sessions. The DSO-R model ensures better utilization

**Figure 8—ROC Curve to Check Prediction Accuracy for the Testing Data Set**



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**Figure 9—ROC Curve to Check Prediction Accuracy During the Testing Phase**

Days	Patients Arriving for Telemedicine	Treatment Available	Patient Travels for Further Treatment	Expected Total Loss in US Dollars (\$)
1	81	10	5	690
2	86	10	5	737
3	92	11	6	783
4	97	12	6	828
Average expected loss per day =				759.5

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of a telemedicine session, because the probability of the remote organization participating in a particular session has already been obtained. The model facilitates faster decision making in broadcasting telemedicine sessions to selected zone(s) and helps with risk identification by precalculating the expected loss from misclassification by the classification tree.

However, a data set consisting of appropriate hospital names rather than zones will improve the prediction accuracy and, therefore, the expected loss when using the DSO-R model. Future development of the DSO-R model will apply more robust and intelligent machine learning techniques to improve the prediction accuracy. The effect of a miscalculation with field



data will also be tested, which will help with studying relevant factors that can increase or decrease the expected loss of a telemedicine session.

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