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Optimizing the Spare Parts Management Process in a Communication Network

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Abstract In this paper we describe how to improve the spare parts management process in a telecommunications' operator. Several techniques such as: neural networks, analytic hierarchy process, and software agents are used to implement a software prototype that has been validated in an operational environment with a concept trial. Better working conditions were reached by freeing up the technicians for other functions, given that they should not carry out the tedious and stressful activities included in the spare parts process. Such tasks were completed according to the time that was established in the customers' service level agreements to avoid penalties. Operating expenditure was cut in a significant way. An increase of the overall industrial process performance was also accomplished as the spare parts management time dropped. This is, as far as we know, the first time that a combination of these techniques was applied to manage a spare parts inventory and prioritize incidents in such a complex scenario as the optical transmission network of a major telecommunications' operator. The framework might be used in other domains such as: the hardware replacements that are required in some critical operational environments.

Keywords Industry application · Knowledge based systems · Neural network applications · Software agent · Management

Neither the entire paper nor any part of its content has been published or has been accepted for publication elsewhere. It has not been submitted to any other journal.

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1 Introduction

A transmission network is the basis of the telecommunications business. All services: voice, data, internet protocol television (IPTV) or wireless telephony rely on a transmission network that is able to handle very high amounts of information in a safe and trustworthy manner. SDH is the nucleus of this network, along with the use of WDM systems with long distance routes. An optimal spare parts management process (SPMP) is required in any telecommunications' operator to guarantee that all necessary spare parts (e.g. network cards) are available on time without big inventory costs in order to achieve the service level agreements (SLA) and to prevent penalties by the regulatory body.

By means of the SPMP new spare parts are received, stocked, registered, and controlled to ensure the inventory quality and the detection of new needs for the procurement. The stock figures are determined by the available budget for acquisitions, the lifespan, the stock age, and the amount of spare parts. Planning for procurement, which is adjusted according to elapsed time between ordering spare parts and receiving them, is made before the spare parts are reduced to minimum stocks. However, some problems exist in this SPMP: Many tasks are carried out manually by the technicians (information look-ups, processing of forms and email, updates in corporate systems, incident severity assignments, etc.), and replacement needs are calculated with too broad of a scope, and the inventory presents a poor quality due to misaligments with the deployed network. All these facts mean that a lot of time passes before the problems can be solved. Because relevant penalties are imposed to the telecommunications' operator by the regulatory body when the customers' SLAs are not fulfilled, the technicians should perform the card replacements as soon as possible while continually working under stressful conditions.

This research has been validated in a large transmission network [1] with a concept trial that uses human cognition to automatically manage the card replacements in a national network with 245,644 network equipments (NE), 51 network element managers (NEM), 435,876 paths, 12,216,030 circuits, and 41,466 physical links. By using the prototype, the conditions at work improved and the process performance significantly increased. The following actions were carried out:

- The full SPMP was analyzed in order to know all tasks performed during a working day in detail and to detect pain points. Any of the activities, which were always carried out according to specific factors, might be characterized as automated, as long as they were also characterized as pain points. Some repetitive tasks were automated such as spare part lookups, generation of purchase orders, delivery of email messages, assignments of incident severity, audits on deployed and uncatalogued cards, and spare parts consumption forecasting.
- IT experts provided important insight into the decision-making process by adding a key perspective that helped decide where to proceed with automation and where to hold back in order to prevent disruption.

- New process strategy identification was developed not only to support the automation effectively, but also to identify the new responsibilities that technicians had to take on in their free time as their work procedures were modified.

This research uses the NN [2] approach to foresee the demand: the AHP [3, 4], and SA to automatically decide the critical nature of the incidents and SA to automate the SPMP in the SDH and WDM networks of a big telecommunications' operator. Although there is no previous work on applications that use the aforementioned framework in these networks, there are some pieces of research in other fields, and some of them are

- In [5], the authors present an interview protocol for group knowledge elicitation that uses AHP for nuclear spare parts inventory management. Their goal was to develop a spare parts inventory model that mitigates the risk of revenue loss from off-lining the plant. Inconsistencies in the data and challenges in the AHP group aggregation are also examined. A numerical example of employee responses is included.
- In [6], a comparative study is performed with simulated data to show that the NN can be a promising tool to conventional methods (such as the Croston method) for predicting intermittent demand in terms of two criteria: mean squared error (MSE) and mean absolute error (MAE). To show that the proposed NN model can provide better results with respect to demand forecasting, random time series data sets have been generated that include both training and validating steps.
- In [7], the authors propose a two-stage method to effectively predict the requirements of electrical critical spare parts utilizing particle swarm optimization and Fuzzy NN to provide an example of spare parts control. The paper also compares prediction accuracy with other forecasting methods such as double exponential smoothing, moving average, and traditional feedforward NN, etc. All of the forecasting methods are tested in an empirical, comparative study for an electric power supply company in China. The results show that the two-stage approach is one of the most accurate methods.
- In [8], a logistic cycle of spare parts for telecommunication equipment is characterized, the importance of each process and the required discipline in the control of every item in stock is underlined. The alignment between the decision makers and the choice of relevant criteria that help the decision making are also checked.
- In [9], the author presents an integrated life-cycle demand model and an inventory management framework to improve the service parts demand forecasts. The authors also carry out a small simulation experiment to show the benefits of their approach.

Work based on the case-based reasoning (CBR) and expert systems (ES) approaches exists. Examples include the following:

- In [10], the authors propose the application of the approach of CBR to build a knowledge base of an intelligent system for predictive maintenance of hydropower equipment. The architecture and development to obtain the relational model of the knowledge-base (according to the CBR approach) is summarized in 4 phases: first, identification and classification of hydrogenerator machinery, according to the type or the family of each piece of equipment; second, search and collection of information related to situations of failure or abnormal events that occurred in the equipment of the hydroelectric power plant; third, definition of the structure of the cases focused on the diagnosis of equipment failures and support in making decisions. Finally, the cases are coded and implemented in a relational database (knowledge-base). The obtained results are related and structured in an intelligent system according to the CBR approach with the objectives of fault diagnosis and decision support.
- In [11], an intelligent multivariable decision-making system for mineral grinding process control is proposed with the CBR. This intelligent decision system can auto-adjust the set-points of the process controllers according to the operational conditions. As long as the process control system tracks their adjusted set-points, the closed-loop control of grinding particle size is achieved. The industrial application in a mineral processing plant shows the effectiveness of the proposed approach.
- In [12], a method to solve the main provisioning and deployment problems on a large SDH network is described. The solution is based on an ES that decides the specific actions to carry out on the network management system (NMS) when an error occurs. Some actions are as follows: to execute audity–discovery functions, to relate data in the corporate systems and in the NEM, to check the NEM or NE situation, to stop some tasks in the NMS, to modify the status of some tasks in the NMS, or to retry some tasks later. More than 700 failures were identified that were classified by different types of checking of the vendors' documents.

However, we do not consider the CBR and ES approaches suitable for predicting the spare parts demand and assigning the incident severity in a large transmission network. Regarding the ES approach, the evolution of the spare parts needs and the incidents' criticality cannot usually be explained using expressions represented as the IF-THEN rules. Regarding the CBR method, the required criteria for indexing and matching cases is difficult to determine. If new requirements appear and the most similar cases are not evaluated as similar enough, most analogous cases should be adapted. However, limited mathematical theory exists to provide practical adaptation methods.

This paper is organized as follows: Sect. 2 describes the SPMP, Sect. 3 explains the main problems of the SPMP, Sect. 4 details the proposed technical procedure for resolving them, Sect. 5 explains the obtained results, and the Sect. 6 summarizes the main conclusions.

2 Spare Parts Management Process

If a damaged card exists, an alarm is displayed in the NMS's alerting the operators of the problem. They will report this incident in the incident management system (IMS) to the local operation department (LOD), whose technicians will look up a spare part using the logistic inventory system (LIS). These technicians must request the necessary data for the access; that is, login, password and user profile details. According to their profile, they will be able to consult the territorial or provincial stores. If any spare part is found, they will fill out and send a request form to the main store through the LIS, complying with some requirements about addresses and subjects.

Several queries can be executed in the LIS, such as: the amount of available cards per code, per geographical area, and per catalogue. Each network card is identified by means of a code (9 positive numbers) that is obtained from three card features: name, version, and vendor. However, the LIS is often out-of-date because some codes are not catalogued or because some spare parts are marked as available although they are deployed in the plant. These facts are caused by misunderstandings between the logistic department (LD) and the engineering department. An audit procedure must be performed periodically to solve the misalignments by the operation and maintenance department (OMD).

In the case that a spare part is available, the LOD technician sends an email to the LD that must comply with some requirements related to addresses and subject. The LD manages the request and sends a spare part to the LOD. A LOD technician will transport the spare part to the exhange and will update the status of the incident in the IMS. The elapsed time between the LOD technician's request and delivery of the spare parts is around 24 h. However, in the event that a shorter time frame is required due to the problem's severity, an external carrier might be hired by the LD.

If a stock shortage occurs, the LD will manage a purchase order and will buy a spare part. However, if, according to the characteristics of the incident, the spare part is considered urgent (such as: failures that impact the SLA), the LD informs the national control commitee (NCC), which will re-evaluate the incident severity and will send an email to the OMD. In the event that the OMD confirms the failure as urgent, then they will look up a similar card with low traffic that will be rerouted in order to move the card.

3 Problems in the Spare Parts Management Process

The described SPMP in the previous section presents the following problems:

- The decision to buy replacement cards is made considering the existing stock in the main, territorial and provincial stores, the simple moving average method is used to forecast the spare parts consumption. This algorithm is based on the assumption that historical data contain a component of noise that hides the real pattern of the time series. It uses an average of a specified number of the observations with each observation having the same weight. This average is employed as the predictor F_{t+1} for the next period:

$$F_{t+1} = (V_t + V_{t-1} + V_{t-2} + \cdots + V_{t-n+1})/n \quad (1)$$

F_{t+1} is the forecast value in the period $t + 1$, V_t is the observation value in the period t and n represents the number of periods considered in the moving average. The optimal n value is obtained from the smallest mean squared error (MSE). The MSE is calculated from the observations $t + 1$ until w.

$$MSE = \Sigma_{k=t+1}^{w} (F_k - V_k)^2/(w - t) \quad (2)$$

A group of technicians is responsible for taking the purchase decision monthly. They use an Excel file that contains the values V_i per each code card and the calculations previously explained. The values V_i correspond to the monthly demand collected for 2 years for each store. Once the values F_{t+1} per each card code are estimated, the technicians send an email to the LD showing the amount of cards that should be bought. The LD operators will manage the purchase order and will update the LIS with the order date and an expected reception date for each card.

- The NMS is used to manually audit the cards that are deployed in the network without being catalogued in the LIS (periodic inventory control).
- The technicians take a lot of time to carry out several procedures, such as: looking up replacements in inventories, generating purchase orders, sending emails, and determining the incident severity, etc. The establishment of the severity of an incident is not a trivial issue since a thorough analysis can be required to decide its value. The operators might assign incorrect severities due to the little time they have to carry out the dispatch. An erroneous non-critical severity would imply that the necessary tasks to solve the problem would consume more time than those required to minimize the impact on the service. An incident categorized erroneously as critical would cause an inefficient use of resources.

This way of working implies that a lot of time is wasted before the damaged card can be replaced in the network. According to the guidelines provided by the company management, the daily consumed time in each aforementioned task (checking on deployed and uncatalogued cards, anticipating the spare parts demand, looking up a spare part and managing the replacement requests according to the procedures described above) was written by the technicians in their workbooks for 2 years. Later, while the undertaking this research, these data were gathered and registered in Excel files and their monthly average was calculated by the project team. The average time consumed by each task is shown in Table 1 for the detailed network in Table 2; the total task duration in a month was 34,014.4 h. It should be noted that 24-h daily work shifts were established to cover the service requirements (on average, a working month has 30 working days and 720 working hours).

Table 1 Monthly consumed average time according to task

Unit	Task	Subtasks	Monthly average time (h)
OMD	Perform an audit procedure periodically		3204
LD	Anticipate the spare parts demand		7608
LOD	Look up a spare part in the LIS		6202.4
LOD	Manage the spare part request	Fill out a request form and send it to main store by email	17,000
LOD		Send an email to LD asking for an available spare part in territorial or provincial stores	
LD		Manage the requirement from LOD and send the card replacement to LOD	
LOD		Transport the card replacement to the exchange	
LOD		Update the status of the incident in IMS	
LD		Inform NCC when the card replacement is urgent and there are not any spare parts in the stores	
NCC and OMD		Carry out the established procedure for an urgent replacement	

Table 2 Number of equipments according technology

Vendor	WDM	SDH	Total
Huawei	595		595
Telnet		1075	1075
Ericsson	7956	46,179	54,135
Alcatel-Lucent	65,137	124,702	189,839
Total	73,688	171,956	245,644

4 Technical Solution

The development of the technical solution was carried out following a phasing model that was summarized in the initiation, analysis, planning, execution (establishment, realization, hand-over) and conclusion phases. A phase began only when the previous phase was completed; the step by-step nature of this approach allowed minimizing uncertainties. If a problem occurred, it would probably be detected in the initial phases and would be marked for correction. Due to the fact that this approach was very structured, it was easier to evaluate progress by referring to clearly defined millestones.

In the initiation phase, the idea for the execution of this research project was explored and constructed. The goal was to check the viability of the project (who would carry it out, and which stakeholders would be or should be involved).

In the analysis phase, the requirements (preconditions, functional, operational requirements and design limitations) related to the project results were specified. Several techniques and tools to collect requirements were used, such as:

- Interviews to elicit information from technicians by talking to them directly. The responses to prepared and spontaneous questions were recorded.
- A focus group to bring together technicians and experts to gain their expectations and attitudes.
- Facilitated workshops focused on bringing business subject matter experts and the development team together to improve the software development process.

The most relevant requirements identified were

- An easy access to the prototype would be provided to the technicians, who could track the whole spare parts management process from their computers and modify some parameters (for instance, the weights of those criteria used by AHP).
- A reduction higher than 50% should be achieved in the required time:
    - To check the misalignments between the information registered in LIS and the deployed cards in the network,
    - To calculate the demand forecasting,
    - To manage the requests of spare parts.

In the planning phase, several tasks were carried out: review/creation of the project time plan, risk identification and risk management plan construction, cost estimations, staff acquisition, and cost planning.

In the execution phase and during the establishment stage, the list of requirements that was developed during the definition phase was employed to make design choices, such as programming languages to be used, approaches to build replacement demand forecasting (NN, ES, or CBR) and data base technologies (ORACLE [13] or MySQL [14]). All issues that were required to implement the project were arranged as follows: materials were ordered, instructions were given to the personnel, etc. In the execution phase, specifically during the realization stage, the implementation, monitoring, and control, as well as the transfer to the operational environment took place. In the execution phase and during the hand-over stage, several tasks were performed such as writing handbooks, providing instruction and training courses for the technicians, and evaluating the project results.

Finally, in the conclusion phase, the project evaluation and final report creation (lessons learned and improvement plans) took place.

We propose a technical solution that:

- Automatically executes part of the SPMP
- Anticipates the spare parts demand and updates the LIS
- Allows follow-up of the SPMP from the technicians' computers

This technical solution consists of the several elements that are shown in Fig. 1: 4 SA, an ORACLE [13] centralized data base (12c Release 1), and a Java GUI. MQSeries Messaging (version 8.0) [15] and Neuroph (version 2.9) [16] products are used.

Process: Demand Forecast ***(DemForAgent)***

DemForAgent employs MQ series messages and Pro C in order to interact with the corporate systems (LIS) and the data base (DB), respectively. It is written in language JAVA.

This agent aims to prevent stock shortages. It estimates the necessary spare parts based on an NN monthly, sends the requests to the LD by email, and carries out the required adaptations in the LIS. Neuroph Environment is used to construct the NN. This NN framework has been released as an open source software under an Apache 2.0 license, which allows the development of NN architectures; it contains a JAVA library with several basic classes and provides a User Interface (UI) to create the NN components. The NN is modeled as a MultiLayer Perceptron (MLP), where an input vector (X_p) consists of several elements (x_p^j) that represent different card features. N training examples exist $\{X_p, T_p\}_{i=1..N}$, being X_p and T_p the input and the desired output vectors, respectively. This NN executes the following algoritm:

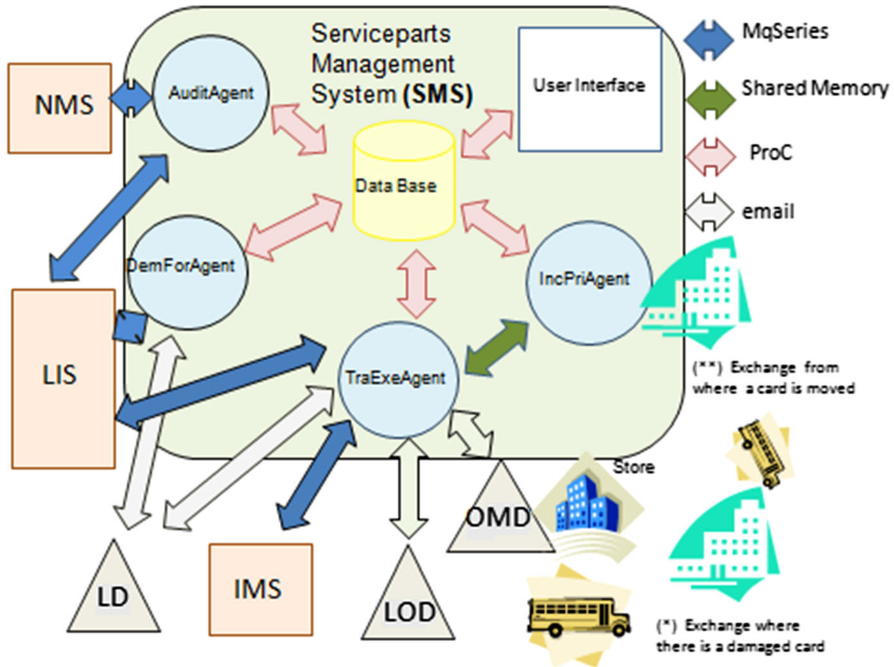

Fig. 1 Architecture of the technical solution

1. *To initialize*
2. *To present a training example* (X_p, T_p),
3. *To carry out the forward propagation;* for each training example (X_p, T_p), the weighted additions are calculated. The weighted addition $v_j(n)$ for the j neuron in the l layer is defined as:

$$v_j^{(l)}(n) = \Sigma_{i=0}^{m} w_{ji}^{(l)}(n) y_i^{(l-1)}(n) \tag{3}$$

where $y_i^{(l-1)}(n)$ is the ouput of the i neuron in the $l-1$ layer in the n iteration, $w_{ji}^{(l)}(n)$ is the weight of the j neuron in the layer l that is fed by the i neuron in the $l-1$ layer, and m is the number of neurons in the $l-1$ layer. We use the sigmoid function as the activation function (φ); therefore, the output of the j neuron in the l layer is

$$y_j^{(l)}(n) = \varphi_j(v_j^{(l)}(n)) \tag{4}$$

If the neuron j is in the input layer, that is, in $l = 0$:

$$y_j^0(n) = x_p^j \tag{5}$$

where x_p^j is the jth element of the input vector X_p. If the neuron is in the output layer, that is, $l = L$, the error is

$$e_j(n) = t_j(n) - y_j^{(L)}(n) \tag{6}$$

where $t_j(n)$ is the jth element of the vector of desired answers (T_p). Figure 2 shows a diagram of connections and weights of an MLP.

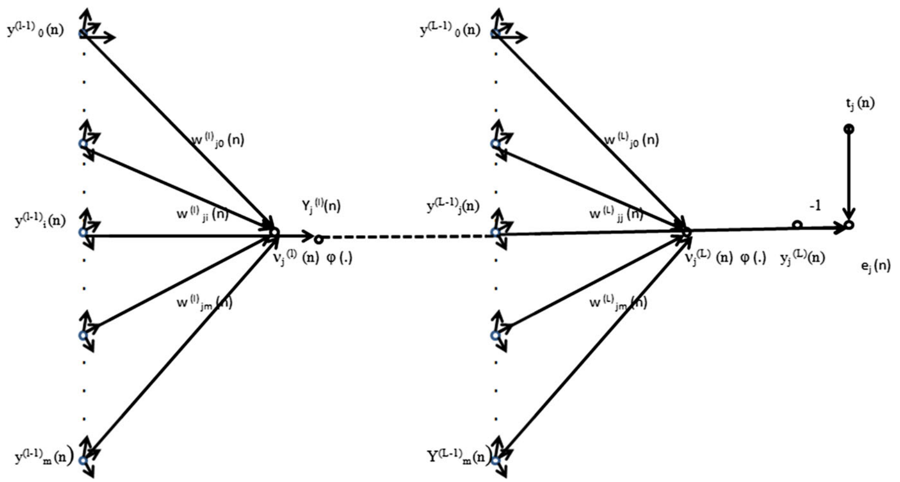

Fig. 2 Diagram of connections and weights of a MLP

4. *Backward propagation* The local gradients are calculated (δ):
   - For the j neuron in the output layer L:

$$\delta_j^{(L)}(n) = e_j^{(L)}(n)\varphi_j^{'}(v_j^{(L)}(n)) \quad (7)$$

   - For the j neuron in the hidden layer l:

$$\delta_j^{(l)}(n) = \varphi^{'}(v_j^{(l)}(n))\Sigma_k\delta_k^{(l+1)}(n)w_{kl}^{(l+1)}(n) \quad (8)$$

   where $\varphi^{'}$ means diferentiation.

   The fitting of the weight networks is carried out according to the generalized delta rule [17]:

$$w_{ji}^{(l)}(n+1) = w_{ji}^{(l)}(n) - \eta\delta_j^{(l)}(n)y_i^{(l-1)}(n) \quad (9)$$

   where η is the learning rate.
   Figure 3 shows a schematic representation of the backward propagation of the errors in a neuron where the NN has an output layer with R neurons.
5. To return to point 2 until the established value for the MSE is fulfilled.

$$MSE = \frac{1}{N}\Sigma_n\frac{1}{2}\Sigma_j e_j^2(n) \quad (10)$$

Historical data related to cards are used as input to the NN, such as model, average lifespan, delivery date, number of cards that have identical model, amount

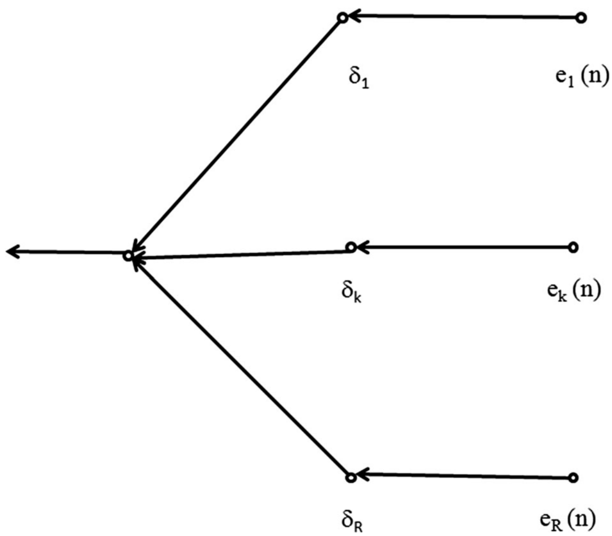

Fig. 3 Schematic representation of the backward propagation of the errors in a neuron, where the NN has an output layer with R neurons

of spare parts in the stores, and finally, elapsed time since the last card replacement. These data define the coordinates x_p^j of a training vector X_p. To start the training process, the weights are chosen randomly. We provide the desired output and input. The network then processes the input and compares the resulting output with the desired output. Errors are then propagated backwards and the system adjusts the weights that control the NN. This process happens over and over as the weights are slightly modified. During the training process, the same set of data is processed many times as the connection weights are constantly refined.

The NN consists of four layers of nodes: the input layer, 2 hidden layers, and the output layer. The input and the hidden layers have 10 nodes while the output layer has only one node. The network is fully connected. 12,398 input vectors were used, which correspond to monthly observations collected during 2 years. The last 4119 input vectors were reserved for testing, which meant that the remaining 8279 input vectors formed the training set. After 17,162 iterations, the MSE of the training set and test was 0.025640 and 0.025785, respectively. The training was stopped after 17,162 iterations as there was no significant decrease in either MSE errors. The learning rate, η parameter in Eq. (9), was 0.015092.

Process: Incidents Priorization *(IncPriAgent)*

IncPriAgent employs memory sharing and Pro C in order to interact with *TraExeAgent* and the DB. It is written in language C++.

This agent collects the received incidents every hour and uses the AHP to determine their critical nature. The AHP was developed by Saaty in [3] and [4] as a way of dealing with weapons tradeoffs, resource and asset allocation, and decision making. Four hierarchy tiers are defined in the technical solution:

- The first level is designed to select the most urgent incident, or the one that corresponds to the most urgent failure.
- The second and third levels are the criteria, or those relevant features in the incidents. So, the more general criteria are in the second level, such as: customer segment, number of subscriber lines impacted by the failure, creation date, and finally, the province in Spain where the problem occured. In the third level, there are some more specific criteria, such as large-scale customers, like corporations; the general public; or small and medium-sized enterprises. The criteria are flexible and configurable since they can be activated and updated in the UI.
- The fourth level refers to the alternatives, that is, the incidents received from the IMS.

In Saaty's method [3, 4], n criteria $C_1 \ldots C_n$ are taken into account to compare the relative weight of C_i with respect to C_j. This is represented by a_{ij} and a square matrix $A = (a_{ij})$ of order n built with the constraints that $a_{ij} = 1/a_{ji}$, given that $i \neq j$, and $a_{ii} = 1$, all i. Such a matrix is said to be a "reciprocal matrix". Weights are consistent if they are transitive, that is $a_{ik} = a_{ij}a_{jk}$ for all i, j, and k. A vector w of order n exists so that $Aw = \lambda$. This matrix, w, is called an "eigenvector" (of order n) and λ is an "eigenvalue". The w vector satisfies the equation $Aw = \lambda_{max} w$ and $\lambda_{max} \geq n$. A consistency index (CI) and a consistency ratio (CR) are calculated. CI is

Table 3 CI calculated for a random matrix of order n

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

computed as $(\lambda_{max} - n)/(n - 1)$. *CR* is estimated by dividing the *CI* by the *CI* calculated for a random matrix of order *n* according to Table 3 [3]. In this table, the upper and lower rows correspond to the order and CI of the random matrix.

According to the previous description, once the hierarchy has been established, we can determine the relative importance of the element in each level of the hierarchy. The elements in each level are compared against each other in accordance to their importance in making the decision under consideration. The descriptive preferences between every two elements are translated into absolute numbers using a scale from 1 to 9 and registered in the UI by the technical experts. According to the procedure described in [3] and [4], after constructing the comparison matrices, the relative weights of the elements of each level with respect to an element in the adjacent upper level are calculated as the components of the normalized eigenvector associated with the largest eigenvalue of their comparison matrix. The composite weights of the decision alternatives are then calculated by aggregating the weights through the hierarchy. This is done by following a path from the top of the hierarchy to each alternative at the lowest level and multiplying the weights along each segment of the path. The result of this aggregation is a normalized vector of the overall weights of the options. If several incidents have identical severity according to the AHP, these incidents will be attended to by taking into account the specific time at which they occurred. If both incidents occurred simultaneously they will be selected at random.

Next, we describe a schematic example of the execution of AHP: Fig. 4 depicts the hierarchy tiers, the criteria, and the possible choices. Thus, C_1, C_2, C_3, and C_4 criteria correspond to customer segments, the number of subscriber lines impacted by the failure, the time in which the incident was created in IMS and the province where the problem happened. C_{11}, C_{12}, and C_{13} criteria symbolize the customer segments, such as large-scale customers, the general public, or small and medium-sized enterprises. The C_{21}, C_{22}, and C_{23} criteria refer to the number of subscribers impacted by the problem, specifically over 199, between 50 and 199, and between 1 and 49. The C_{31}, C_{32}, and C_{33} criteria refer to the time in which the incident was created in IMS, that is, today, yesterday, or any other time. The C_{41}, C_{42}, and C_{43} criteria correspond to Madrid, Baleares, or any other province in which the failure happens. Table 4 displays the paired comparison matrix in level 2 with respect to level 1, showing, in particular, that the normalized eigenvector of the relative importance of C_1, C_2, C_3, and C_4 is 58.31, 28.95, 8.49, and 4.25%, respectively. The obtained consistency index (CI) and consistency ratio (CR) are thus 0.0548589 and 0.060954. Tables 5, 6, 7 and 8 show the paired comparison matrix in level 3 with respect to each criterion C_1, C_2, C_3, and C_4 in level 2. The normalized eigenvector of the relative importance of criteria in level 3, in relation to criteria in level 2, is also shown. For example, C_{11}, C_{12}, and C_{13} have an importance of 51.46, 38.79, and

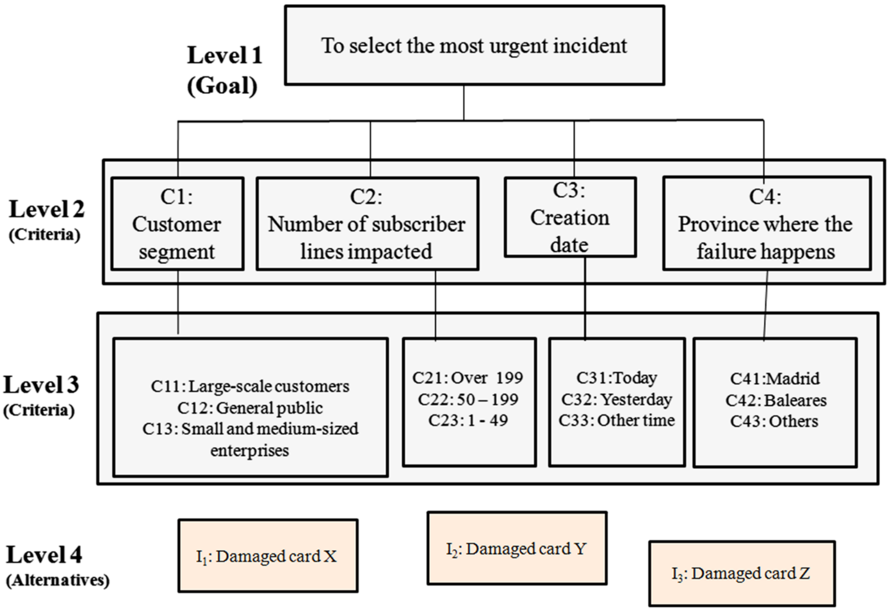

Fig. 4 Hierarchy tiers in AHP

Table 4 Paired comparison matrix level 2 with respect to the goal

Criteria	C_1	C_2	C_3	C_4	Normalized eigenvector (%)
C_1	1	3	7	9	58.31
C_2	1/3	1	5	7	28.95
C_3	1/7	1/5	1	3	8.49
C_4	1/9	1/7	1/3	1	4.25

Table 5 Paired comparison matrix level 3 with respect to C1

Criteria	C_{11}	C_{12}	C_{13}	Normalized eigenvector (%)
C_{11}	1	1	7	51.46
C_{12}	1	1	3	38.79
C_{13}	1/7	1/3	1	9.75

Table 6 Paired comparison matrix level 3 with respect to C2

Criteria	C_{21}	C_{22}	C_{23}	Normalized eigenvector (%)
C_{21}	1	1/5	1/2	11.25
C_{22}	5	1	5	70.89
C_{23}	2	1/5	1	17.86

9.75% with respect to C_1 (CI = 0.040145; CR = 0.069216). C_{21}, C_{22}, and C_{23} have a relevance of 11.25, 70.89 and 17.86% with respect to C_2 (CI = 0.026811; CR = 0.046226). C_{31}, C_{32}, and C_{33} have a significance of 79.59, 12.12 and 8.30%

Table 7 Paired comparison matrix level 3 with respect to C3

Criteria	C_{31}	C_{32}	C_{33}	Normalized eigenvector (%)
C_{31}	1	9	7	79.59
C_{32}	1/9	1	2	12.12
C_{33}	1/7	1/2	1	8.30

Table 8 Paired comparison matrix level 3 with respect to C4

Criteria	C_{41}	C_{42}	C_{43}	Normalized eigenvector (%)
C_{41}	1	1/3	7	29.66
C_{42}	3	1	8	64.50
C_{43}	1/7	1/8	1	5.84

with respect to C_3 (CI = 0.049967; CR = 0.08615) and finally, C_{41}, C_{42}, and C_{43} an importance of 29.66, 64.50 and 5.84% with respect to C_4 (CI = 0.052191; CR = 0.089984). Suppose that technicians should solve three incidents I_1, I_2, and I_3. I_1 refers to a an incident with a large-scale customer, impacting 300 subscriber lines and happening in Madrid today. I_2 impacts a general public segment customer, 66 subscriber lines, and occured in Baleares yesterday. Finally, I_3 is related to a small-sized enterprise, impacting 20 subscriber lines, and happened in Barcelona some time before yesterday. Then, we compute the overall weight of each alternative choice (I_1, I_2, and I_3) based on the weight of level 2 and level 3.

$$\begin{aligned} I_1 &= 58.31\% \times 51.46\% + 28.95\% \times 11.25\% + 8.49\% \times 79.59\% + 4.25\% \times 29.66\% \\ &= 41.28\%. \\ I_2 &= 58.31\% \times 38.79\% + 28.95\% \times 70.89\% + 8.49\% \times 12.12\% + 4.25\% \times 64.50\% \\ &= 46.91\%. \\ I_3 &= 58.31\% \times 9.75\% + 28.95\% \times 17.86\% + 8.49\% \times 8.30\% + 4.25\% \times 5.84\% \\ &= 11.81\%. \end{aligned}$$

From this example, we can come to the conclusion that I_2 is the best choice, followed by I_1. The worst choice is I_3.

Process: Transactions Execution ***(TraExeAgent)***

This agent manages those incidents related to damaged cards. The *TraExeAgent* employs memory sharing, MQSeries messages, and Pro C in order to interact with *IncPriAgent*, the corporate systems (IMS and LIS) and the DB.

If the *TraExeAgent* receives an incident from the IMS, it exchanges information with *IncPriAgent* and with LIS to classify the incident severity, and look up a spare part according to the damaged card characteristics (in both territorial and provincial stores). In the case that a spare part is found, the *TraExeAgent* chooses the closest store to the exchange where the problem happened, updates the LIS, and sends an email to the LD. A carrier (internal or external) will pick up and deliver the spare part to the exchange. However, if there is not an available spare part in the aforementioned stores, the *TraExeAgent* completes and sends the request form to the

LIS for the main store. If there is not a spare part in the main store and the severity level of the incident is critical, the *TraExeAgent* sends an email to the OMD that will search for a similar card in other exchanges (it should be highlighted that it is not necessary that LD informs the NCC to re-evaluate the incident severity). An LOD technician will arrive at this exchange, where they will reroute the traffic and remove the card. The OMD will send this card to the exchange where the damaged card must be replaced. In any case, if there is not a spare part in the main store, a new card must be bought.

Process: Audit ***(AuditAgent)***

AuditAgent employs MQ Series in order to interact with the corporate systems (LIS) and the NMS. It uses Pro C to dialogue with the DB. This agent is written in language C++.

AuditAgent verifies the alignment between the LIS and the network, twice per month, and obtains information from the NMS related to the cards of each network element manager (NEM): location (rack, subrack, slot), date on which they were deployed, model, serial number, version, vendor and spare part code. This agent then updates the information in the DB for all NEM and registers the spare part codes in the LIS according to the deployed resources. The DB also contains information about the location of the NEM, that is, the province, name, and identifier code of the exchange that is obtained by this agent from NMS.

User Interface ***(UI)***

It is a simple and intuitive interface, based on well-known JAVA technology that allows access to the spare parts management system (SMS) from any point of the telecommunication operator's network and defines operating profiles adapted to each user. Technicians' computers should have a web browser installed, whereby they will be able to follow up the SPMP and construct bookmarks to consult the information. An essential requirement of the prototype is to reduce the training time of new users. The following reports exist

- Spare parts forecast per store that show the total amount of spare parts and the estimated reception date on which each spare part will be received
- Applications per store that display information related to each request, such as: request identifier, associated incident, spare part code, date, request status ('P': pending, 'D': delivered, 'UD': undelivered, 'NA': not available), and finally, all stores where the spare part is available
- Misalignment with the network reports that show all unexisting cards codes in the LIS
- Exhanges where a specific card is deployed, and that display the identifier, the name of the exchange, and the province where the card is located.

5 Results

A prototype SMS was designed and installed in a machine with the following features: 5 CPUS (Intel Xeon E5-2643v3@3.40 GHz), 20 GB DDR4 RAM, and 500 GB of hard disk. This transmission network, which consists of equipment of several vendors (Nortel, Alcatel-Lucent, Ericsson, and Huawei) and different technologies (SDH, WDM) has the following features:

- 245,544 NE, 51 NEM, 435,876 paths, 12,216,030 circuits, and 41,466 physical links. The amount of equipment according technology are shown in Table 2
- 1,650,728 cards exist in the network
- On average, 400,000 alarms appear in this network during a day that are correlated into 8000 root alarms that correspond to 600 network problems (80 related to damaged cards).

The SMS was used during the course of 8 months. The obtained results are shown in Table 9. The time consumed daily in each task was written by the technicians in Excel files and their monthly average was estimated by the project team. We observed that a revelevant improvement in the SPMP was achieved; specifically, a reduction of 99.99% in audits, in anticipating the spare parts demand and in the execution of queries in the LIS, along with a shortening of 86.21% in the time taken to manage the requests. It should be noted that senior management wanted to evaluate precisely the improvements in the SPMP attributable to the use of the trial. Due to this fact, no other changes impacting the SPMP were carried out during the execution of the project.

Table 9 Monthly consumed average time according task

Unit	Task	Subtasks	Monthly average time (h)
OMD	Perform an audit procedure periodically		0.3204
LD	Anticipates the spare parts demand		0.7608
LOD	Look up a spare part in the LIS		0.6202
LOD	Manage the spare part request	Fill a request from and send it to main store by email	2344
LOD		Send an email to LD asking for an available spare part in territorial or provincial stores	
LD		Manage the requirement from LOD and send the card replacement to LOD	
LOD		Tranport the card replacement to the exchange	
LOD		Update the status of the incident in IMS	
LD		Inform to NCC when the card replacement is urgent and there is not any spare parts in the stores	
NCC and OMD		Carry out the established procedure for an urgent replacement	

Several training courses were provided to the operators in order to enable them to use the trial. New responsibilities in the SPMP were assigned to the technicians once they were able to handle the prototype, such as:

- The whole SPMP monitoring: displaying graphic reports and supervising the possible error messages in the UI. It should be noted that now technicians only interact with the prototype during a working day, in contrast with the numerous tools that they had to employ before the trial.
- Administration task execution (for instance: to install and remove software packages corresponding to new releases, post-installation configurations, creation and elimination of users, etc.).
- Parameter modification, if required, using the UI (for instance, changing the assigned values to the each criterion weight to be used by the AHP).

Other roles were assigned to several technicians in other company areas. Some operators resisted the advent of SMS because they saw its usage as a threat to their position in the company given that the prototype carried out their daily tasks. They feared the decisions on resource utilization from management level. However

- Company management saw this investigation as a good opportunity for OPEX reduction.
- Fast execution of card replacements were considered a competitive advantage by the company management.
- The operative efficiency was increased due to the automatization process (reduction of human errors, for instance, those caused by misalignments between the LIS and the deployed network.).

Once the project was finished, the technicians and the company management were presented with a satisfaction survey for feedback. A high average score was achieved (8, in a grading scale 1–10), some questions were as follows:

- How satisfied are you with the trial?
- To what extent did the trial meet your expectations?
- Imagine a trial that is perfect in every respect. How close to this ideal do you find this trial?

After the project was completed, new reports were implemented and additional criteria were included in the AHP to help technicians in the SPMP. The SMS continues in operation today.

6 Future Works

All failures due to damaged cards that usually appear in other networks such as: access networks (wireless, optical, or copper) and core network (asynchronous transfer mode (ATM), internet protocol (IP), ethernet, wireless) could be included in the solution extending the NN and AHP to consider the type and tecnology of the network. However, more historic data should be collected from technicians in order to provide the input vectors for building the training and testing sets to be used by the NN. A new analysis will probably also be required to determine the most suitable criteria and weights to be employed by the AHP. Additionally, an application to provide different reports for mobile devices could be implemented.

Other critical areas that feature repetitive, tedious and stressful tasks could be analyzed to verify the viability of these techniques. SMS could be easily adapted in a different spare parts management context, and no significant changes would be required.

- An NN is not established around rules or coded instructions but assimilates the underlying behavior of the model by examining its input and output values and adjusting the weights between neuron layers. The NN could be easily trained to analyze the new available information.
- The structure of the decision hierarchy should be slightly reviewed. Some existing criteria should be removed while newer ones should be added to the AHP.
- However, the interactions with the corporate systems, the required data to carry out the dialogue, and the events that could happen should be specifically considered for these areas, according to the information provided by expert technicians.

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