Proactive Network and Technical Facilities Monitoring Using Standardized Scorecards

An Operational Practice prepared for SCTE/ISBE by

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1. Introduction

Proper measurement is important in making informed business decisions that improve customer experience. Several studies such as Lartey, McGinn, and Diponzio (2016), and Marut (2016), Snow and Weckman (2016) have repeatedly demonstrated the importance of measurement in telecommunications. Yet, measurement is still a complex issue in the broadband industry due to the plethora of measurement possibilities within this environment. Indeed, every card, port, or sub-channel on any communication device provides a number of measurement opportunities adding to the complexity of measurement in the above stated environment.

The current article presents a simple measurement system that seeks to proactively identify issues on the broadband network infrastructure including technical facilities and resolve them prior to any noticeable impact to customers. By so doing, this article will contribute to the increase in network reliability and availability, the decrease in trouble calls and truck rolls, and the increase in customer satisfaction and loyalty. To achieve its goal, the article presents a set of scorecards deployed by a multiservice operator (MSO) to proactively monitor its data, transport, DOCSIS, video, and telephony networks as well as its technical facilities. It also discusses the key performance indicators (KPI) used for each network and the rationale behind their selection, followed by a presentation of the operational model implemented to ensure proper monitoring. The operational model describes the process and structure that allowed the operator to proactively resolve identified issue. Finally, the article presents some real-life achievements of the standardized scorecard system, providing an opportunity for replication and automation within the industry.

2. Measurement Theory

Knowingly or not, human beings and animals use measurement on a daily basis for differentiation. For example, the biggest and strongest animal rules the pack; the fastest car wins the race. As explained by Tao (2011), measuring is a fundamental concept in Euclidean geometry. In that regard, a solid body can be measured in three different dimensions, respectively using the length on one dimension, the area on two dimensions, and the volume on three dimensions. The notion that every physical item has a value that can be measured without significantly influencing the item is well accepted in classical physics under the term *measurement theory*.

Measurement theory is the part of physical theory that determines the empirical and operational content of concepts used. Busch and Lahti (2008) posit that measurements are both operational procedures and physical processes. As operational procedures, they define the observables of the theory and as physical processes, they are also subject to the laws of physics. Some examples of measurement presented by Roberts (2009) includes brightness, intelligence, loudness, mass, preference, and temperature. Roberts puts temperature and mass in the well-developed science such as physics; he classifies intelligence as measurement in less-well-developed sciences such as psychology.

The theory of measurement is extensively discussed by Hand (1996) in his article “Statistics and the Theory of Measurement” published in the Journal of Royal Statistical Society. Confirming what precedes, Hand identifies three categories of measurement theory namely (1) representational measurement theory, (2) operational measurement theory, and (3) classical and other theories of measurement.

Representational measurement theory seeks to numerically represent attributes of objects, events, and even substances. In the creation of the standardized scorecard, individual measurements are taken from devices or obtained through a physical measurement activity. For example, the number of available rack spaces is an example of application of the representation measurement theory.

Operational measurement theory defines measurements in terms of specific operations that produce a number. An example of the application of this theory is the scorecard discussed in this article. Indeed, the scorecard takes a number of measurements and produces the overall score based on an internal process using weighted scores of identified categories.

Classical and other theories of measurement are concerned with subjective interpretations among others. An example of application is the determination of the cleanliness of a technical facility, which is a subjective judgement of the site's cleanliness.

All these categories of measurement theory have various schools of thought. In the broadband industry, various measurements exist such as signal level, noise level, speed, or bandwidth. The measurement retained will depend on the selected application and usage.

3. Key Performance Metrics Used

This article discusses network and technical facilities monitoring in a cable broadband organization also known as MSO or multiservice operator. In such setting, three main services are delivered to the end customers namely data, voice, and video services (Lartey, McGinn, & Diponzio, 2016). Data services mainly include Internet connections at various speeds, up to and even greater than one gigabit per second. Video services encompass audio visual programs sent to the end users using broadcast or narrowcast technologies. Voice services provide phone functionalities to customers using circuit or packet switching technologies. All these services are generally aggregated within a master telecommunications center (MTC) which can also be classified or called secondary telecommunications center (STC), regional data center (RDC), hub, head end, or simply technical facility depending on the size, functionality, and location of the facility on the network. Most networks are constructed in a 4-level hierarchy: national, regional, metro, and access as shown on figure 1 and confirmed by Noll (n.s.) and Schmitt (2012). Technical facilities house the inside plant (ISP) portion of the network and are the purpose of this article. Elements related to the outside plant (OSP) might be mentioned here but are not the focus of the article.

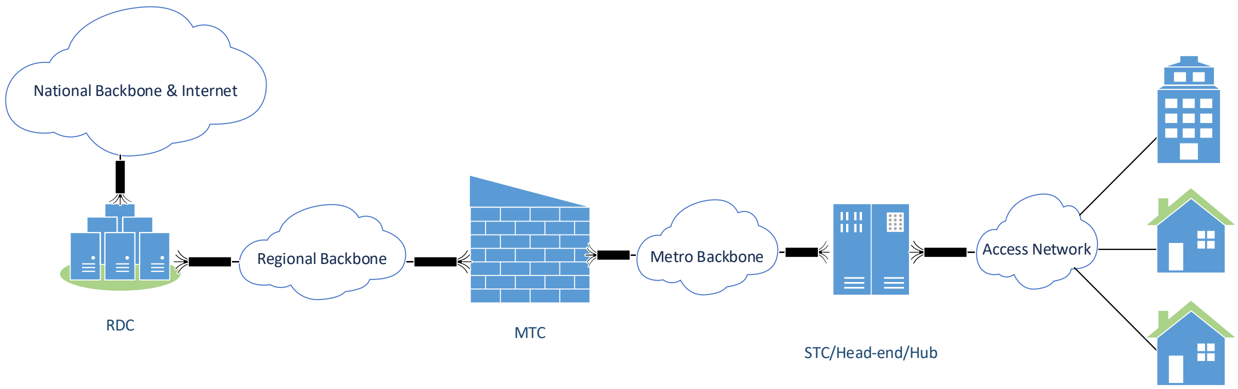

Figure 1 - Representation of a broadband network

1. Technical Facilities

A technical facility houses all the equipment necessary to the good functioning of a network, including power and cooling required for the equipment, hence the name critical system facility. Devices in a technical facility need power. This is generally provided in three main forms: commercial, generated, or stored. Commercial power is provided by the power company and the amount of power entering the facility should support its peak load. For that reason, the operator should have an acceptable indicator of the total power consumed in every technical facility. This metric is important in preventing overheating and other catastrophic events as explained by Rasmussen (2012).

Generated power is produced by a generator on site. Depending on the sizes of the facility, there can be as many as two or three redundant generators or even none. In situations where there is no generator, a good practice consists of prewiring the facility with a special connector for a portable generator. In the event of a power outage, the facility functions on battery until a generator is brought on site. Just as with commercial power, the generator should be sized to support the peak load of the facility.

For its proper operation, a technical facility needs to store power to use as needed. That can be achieved using an uninterruptible power source (UPS) or a bay of batteries. Like with commercial power and generators, stored power can support a given load needing to be measured.

Every device in a technical facility is powered using either alternating current (AC) or direct current (DC). In general, both types of current are needed in a technical facility. Indeed, some network devices operate on DC while others operate on AC power. Inverters and rectifiers are needed for proper AC and DC powering in a facility. Inverters convert AC to DC while rectifiers produce AC either from commercial power, generator, or batteries. The overall relationship is depicted in figure 2.

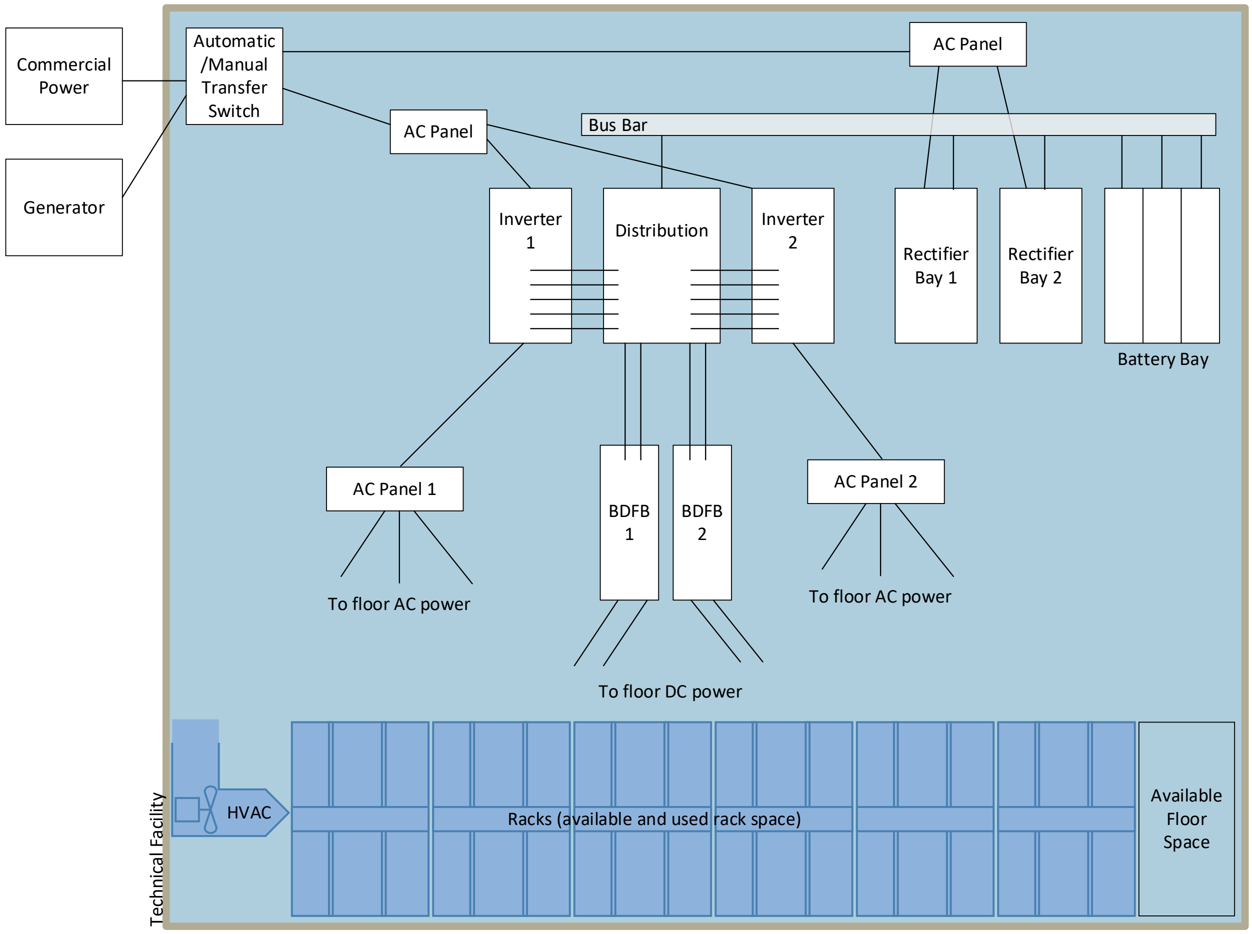

Figure 2 - Technical facility components

By using power, all devices in the technical facility produce a quantity of heat. It is thus necessary to have a heating, ventilation, and air conditioning system (HVAC) for continuous operation of the devices. To ensure these devices will run appropriately during periods of intense heat, the capacity of the HVAC needs to be appropriate and depending on the criticality of the facility, redundant HVAC systems could be required.

Regardless of its size, the availability of rack space or floor space is an important indicator in a critical facility. This metric is useful when new equipment needs to be installed or when an obsolete equipment is replaced by a newer and larger one. In addition, because cleanliness is key in the proper operation of equipment, it is a metric to consider. In the case presented here, cleanliness was added as a subjective observation. The role of technical facilities being to enable network continuity, technical facilities are inter-connected on the network. Each facility houses the necessary devices allowing the propagation of information on various networks such as data, transport, data over network system interface specification (DOCSIS), video on demand (VOD), switched digital video (SDV), telephony, and much more. The overall scorecard also includes measurements of these networks and their related devices.

2. Data Network

The data network is composed of interconnected switches and routers residing in different technical facilities. Traffic from various devices are aggregated by switches and sent to routers to be forwarded across the network routing boundary onto different locations including the Internet. As a result, if a port on the router is congested and depending on the configuration, traffic starts getting slower due to packet retransmission. A congested router port in the headend has the potential of creating bad customer experience due to slow traffic. For this reason, the data scorecard identifies routers of importance and captures information related to port capacity and utilization.

Network growth being a constant with today's bandwidth hungry applications, port availability could be a metric to consider. While the current scorecard did not take this metric into account, it is good practice to include such measurement for awareness. Nonetheless, its absence did not impact the proactive nature of this system because problems where identified long enough to take the necessary corrective actions.

As a summary, the data scorecard used the router ports' bandwidth utilization as the main metric. It identified the main system routers in every technical facility, the ports carrying the main payloads, and captured the values related to the traffic on these ports.

3. Transport Network

The transport network helps interconnect technical facilities using technologies that allow information transportation over very long distances. Such technologies include synchronous optical network (SONET), dense wavelength division multiplexing (DWDM), time division multiplexing (TDM), optical transport network (OTN), and much more. The medium of choice is the fiber optic cable for long distances and local cross-connects, even though copper cables are also used for local cross-connects. The transport network provides various functionalities including information transport, multiplexing, redundancy in case of fiber cut, switching, and management.

The main transport equipment on the network is an optical network element (ONE). Examples of network elements include as the Cisco ONS 15454 SONET/SDH multiservice transport platform (MSTP), the Cisco ONS 15600 multiservice switching platform (MSSP) (Cisco, n.s.), the Fujitsu Flashwave 9500 Packet Optical Networking Platform, and the Fujitsu Flashwave 7500 metro/regional multiservice ROADM or reconfigurable optical add drop multiplexer (Fujitsu, n.s.), just to name a few elements used in the case presented in this article.

On the network considered here, information is transmitted between optical network elements through the DWDM system. The system uses 40 wavelengths also known as lambdas of 10G, 40G, 100G, OC48, and OC192. For that reason, the number of available wavelengths was a metric used in the scorecard.

Knowing that a wavelength could transport Ethernet or an optical carrier (OC) signal, the transport scorecard would measure an OC wavelength deeper and leave the Ethernet carrier to be measured by the data scorecard at the router's port. As such, besides identifying critical circuits and measuring their available lambdas, the transport scorecard also measured available synchronous transport signal (STS) in optical carriers and available cross-connects in network elements.

4. DOCSIS Network

The Data Over Cable System Interface Specification (DOCSIS) network is also known as the Cable Modem Termination System (CMTS) network. Its main role is to provide Internet to residential as well as commercial customers. DOCSIS is a protocol developed by CableLabs to specify communication on the hybrid fiber coaxial (HFC) cable at the data link layer of the OSI model as well as the physical layer (signal modulation and transmission). The CMTS is a network device that controls all communications on the DOCSIS network. Example of CMTS devices include the Cisco uBR10000 (Cisco 10K), Arris C4, Casa C3000 series, and Motorola BSR 64000 just to name a few. New versions of CMTS are known under the acronym CCAP or Converged Cable Access Platform. The CCAP decentralizes some functions of the CMTS, offers video distribution, and supports DOCSIS version 3.1 that currently provides up to a gigabit per second of Internet bandwidth to end users (Sundaresan, 2015). Examples of CCAP include Cisco's CBR-8 and Casa's C100G.

One CMTS serves many HFC nodes and every node serves many homes and businesses. In the case presented in this article, an HFC node served an average of 550 homes, with some nodes serving over a thousand homes. The main issue on the CMTS network is congestion due to shared bandwidth which creates a negative customer experience. As such, a proactive way of improving customer experience is to identify congestion prior to observable effects to customers and the metric retained for this measurement is bandwidth utilization.

5. Video Network

The video network allows operators to acquire, process, and transmit video to subscribers over the HFC network using the same plant as that used for the CMTS network. Video services include broadcast and on-demand services. In the broadcast category, a copy of a specific program is sent to all subscribers at the same time. In this configuration, all subscribers see the same program and the same advertisements as they are sent over the network. Vasudevan, Liu, and Kollmansberger (2008) identify two types of broadcast services namely digital broadcast and switched digital video. Digital broadcast sends all video programs to the subscribers' set-top box (STB), while switched digital video (SDV) sends video programs when a subscriber or the group of subscribers request it. With this technique, SDV optimizes the use of the spectrum because it allocates frequencies on the spectrum only to channels that are being watched. Even though SDV optimizes the use of spectrum, proper allocation needs to be made or customers might experience poor services where they cannot tune to the desired program and have to keep trying until bandwidth becomes available. For that reason, the scorecard includes bandwidth utilization by service group (SG) as key metric for SDV.

On-demand services are different from broadcast services in the sense that the requested program is sent to only one subscriber. In their article on IPTV architecture for cable systems, Vasudevan, Liu, and Kollmansberger (2008) identify two types of on-demand services namely video on demand (VOD) and network-based personal video recorder (nPVR) which is also known as cloud DVR. nPVR was not considered for the scorecard because the network presented here used DVR (digital video recording) which stored recorded programs directly on the recorder and did not require network access to watch them.

Video on demand (VOD) stores movies on a server on the network and when a subscriber selects a movie to watch, the content streams to the subscriber's STB where the movie is displayed on the screen. In this configuration, bandwidth is allocated on the network for that movie alone. If there is no bandwidth available, the subscriber would have to try over and over, creating a negative customer experience. For that reason, bandwidth utilization on the VOD network was retained as key metric on the scorecard.

6. Telephony Network

The telephony network allows phone subscribers to call other phone subscribers or to receive phone calls from anywhere in the world. The phone subscribers in the case presented here are connected to the network by the same HFC plant used for the data and video networks. Just like the other networks, the telephony network contains interconnected network elements that process and transport voice information, connecting a caller to a recipient who could be on off network. Some of these network elements include the main switches, the gateways, and the cross-connects.

In the network of interest by this article, there were many Digital Multiplex Systems (DMS) and CallServer 2000 (CS2K) switches. Along with the switches were the Tellabs Titan 5500 Digital Cross-Connect System (DCS/DACS), the Tellabs Titan 532 DACS, and the Nuera gateways 4K and 8K. To ensure good customer experience, all these elements needed to be measured. For the DMS/CS2K, the selected metrics included SPM (spectrum peripheral module) port availability, IWSPM (interworking spectrum peripheral module) peak utilization, end point capacity, TVCID AIN triggers (television caller identification advanced intelligent network trigger), and SIP SOC RTU peak utilization (session initiation protocol - software optionality control - right-to-use). These were identified as metrics properly addressing the performance and capacity of the switches.

For the gateway controllers (GWC), the metrics selected were the trunk side GWC BHCA (busy hour call attempts) utilization and the line side utilization. For each 5500 DACS, the number of STS available was the key metric and for the 532 DACS, the number of available ports was the key metric of capacity and utilization.

7. RF Spectrum

All three services provided by the MSO (Internet/data, video, and phone) are simultaneously delivered to the end customer using the same medium: the coaxial cable (Lartey, 2015). Regardless of the medium, signal is always transmitted on specific frequencies; a frequency being the speed of the vibration or number of wave cycles in one second. For example, sounds audible to human beings are generally accepted to be in the frequency range between 20 and 20,000 hertz (Hass, 2003). The hertz (Hz) is the measurement unit of frequency and 20,000 Hz is the same as 20 KHz (Kilo Hertz). Figure 2 represents a wave cycle and figure 3 shows an example of a signal being propagated at the speed of 3Hz or 3 wave cycles per second. In the millions, the frequency is expressed in megahertz (MHz) and in the thousands of millions, it is expressed in gigahertz (GHz).

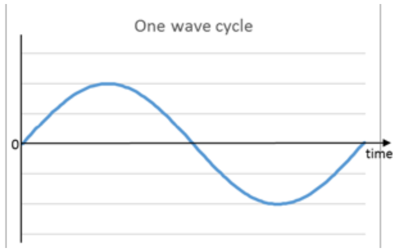

Figure 3 - Representation of a wave cycle for information transmission

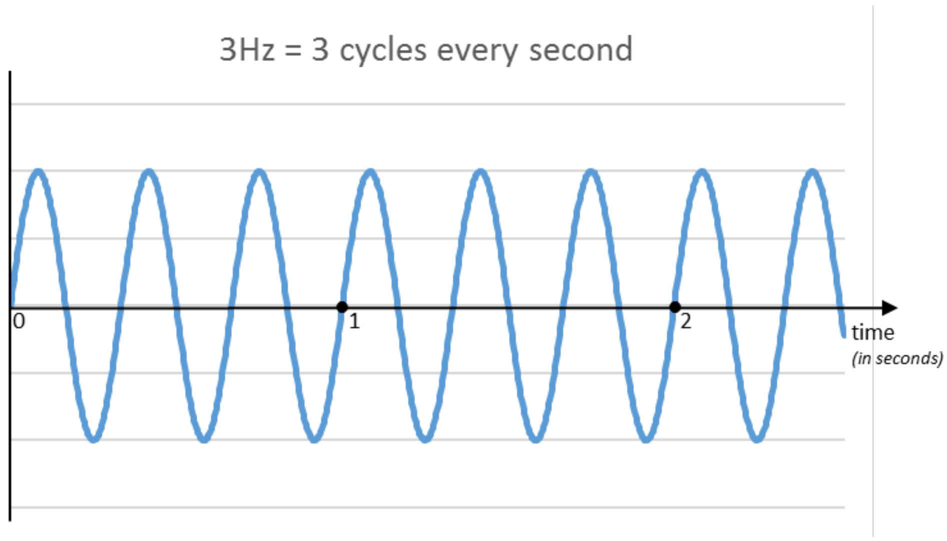

Figure 4 - Representation of a signal with a frequency of 3 Hz

Just like any communication medium, the coaxial cable allows the transmission of analog signal on different frequencies. A range of frequencies is known as a spectrum and the HFC plant currently operates on frequencies between 5 MHz and 1 GHz upgradable to 1.2 GHz and even 1.8 GHz in the near future (Urban, 2010). Part of this spectrum is used for upstream signals from the subscriber to the headend and the other part is used for downstream communication from the headend to the subscriber. The spectrum from 0 to 5 MHz is generally too noisy and currently unusable. In conventional US DOSCIS networks, the spectrum from 5 to 42 MHz is used for upstream communication while the downstream channels use the spectrum from 54 MHz to 1 GHz. The spectrum from 42 to 54 MHz is used as a guard-band where a diplexer or diplex filter installed in the HFC node separates the upstream return from the downstream service as explained by Watts (2011) and Urban (2010). However, European and contemporary DOCSIS standards offer more variations for frequency spectrum allocation.

Because there is a limited number of usable frequencies on the coaxial plant, managing the spectrum is an important task contributing in improving customer experience. For example, a new television channel or additional DOCSIS bandwidth can be added only if there is available spectrum. For that reason, the HFC spectrum was included in the standardized scorecard and the main metric is the number of available channels. This number is expressed in MHz for the upstream and in 6 MHz chunks for the downstream, assuming SC-QAM. This choice was based on the fact that a 6 MHz spectrum can carry either one analog video program, 12 standard definition video programs, 3 high definition video programs, two 3D television programs, or one DOCSIS channel at 38.8 Mbps. This channel paradigm includes OFDM blocks in DOCSIS 3.1, however that is not currently within the scope of this paper.

4. Detailed Procedure and Results

The scorecard is a measuring system presenting the health of all networks based on the common principle stipulating that "if you cannot measure it, you cannot improve it". Indeed, there needs to be a sense of measurement to determine improvement. Because the broadband infrastructure includes technical facilities and many different networks, there are also different scorecards: one for technical facilities, one for each type of network, one for RF spectrum, and the final system scorecard is a standardization or normalization of all the others. In other words, the following scorecards will be created on a regular basis: (1) technical facilities; (2) data network; (3) transport network; (4) DOCSIS network; (5) video network; (6) telephone network; (7) RF spectrum network; and (8) standardized system scorecard.

Each scorecard uses specific key metrics presented in the previous section. Three scoring states are defined for reporting each metric: green, yellow, or red. The green state means the system is performing as expected for that metric. Yellow means the system is performing below expectations and suggests caution. Red implies that something is wrong and needs to be fixed. Each scoring system is presented in what follows.

1. Technical facilities scoring system

Technical facilities are classified into four tiers based on five main criteria: (1) impact to the network in case of facility failure; (2) monthly recurring revenue (MRR) generated in the area served by the facility; (3) number of customers served by the facility; (4) value of the building constituting the technical facility; and (5) type of equipment and number of DOCSIS serving groups in the technical facility. Table 1 shows an example of classification, with tier-1 sites being the most critical to network operations and customer impact.

Based on the technical facilities classification, a scoring grid was created with points allocated to each key metric by facility tier as shown on table 2. For each facility, every key metric is scored based on the specifications of the telecommunication building critical system tool (TBCST), an example of which is represented on table 3.

Table 1 - Classification of technical facilities in the region

Criteria	Tier-1	Tier-2	Tier-3	Tier-4
Impact of the technical facility in case of catastrophic failure	Significant	Significant	Moderate	Moderate
Revenue or monthly recurring charges (MRC) generated in the area served by the facility (all services).	≥ $2,000,000	≥ $1,000,000 and < $2,000,000	≥$250k and < $1,000,000	N/A

Criteria	Tier-1	Tier-2	Tier-3	Tier-4
Number of customers served by the facility	> 20,000	Between 7,500 and 20,000	> 1,000 and <7,500	N/A
Value of the building (not including equipment housed)	> $1 million	Between $500,000 and $1 million	> $150,000 and < $500,000	N/A
Type of equipment in the facility	Voice Gateway, CS2K, RDC eqt.	≥ 17 CMTS service groups	≥ 1 CMTS service group	N/A

Table 2 - Technical facility scoring grid

Tier - Health	HV AC	Pwr	Gen.	DC Plant	Batt.	UPS / Inv.	Space	Monit.	Clean	Fire Sup.	Score
1 - G	8	6	8	7	7	6	4	2	1	1	50
1 - Y	4	3	4	3	3	3	2	1	0	0	23
1 - R	2	1	2	1	1	1	1	0	0	0	9
2 - G	5	3	5	4	4	3	2	2	1	1	30
2 - Y	2	1	2	2	2	1	1	1	0	0	12
2 - R	1	0	1	1	1	0	0	0	0	0	4
3 - G	2	1	2	2	2	1	2	1	1	1	15
3 - Y	1	0	1	1	1	0	1	0	0	0	5
3 - R	0	0	0	0	0	0	0	0	0	0	0
4 - G	-	1	-	1	1	1	-	-	1	-	5
4 - Y	-	0	-	0	0	0	-	-	0	-	0
4 - R	-	0	-	0	0	0	-	-	0	-	0

Table 3 - Scoring of key metrics

Key Metric	Measurement Unit	Green	Yellow	Red
AC Service (Power)		<60%	60- 80%	>80%
AC Service Main Breaker Size	Amps @ 277/480V, 3 Phase			
	Amps @ 120/208V, 3 Phase			
	Amps @ 120/240, 1 Phase			
Annual Peak Load	Kilowatts			
Generators		<60%	60- 80%	>80%
Generator Capacity	Kilowatts			
DC Plant and Battery		>= 4h	2h - 4h	< 2h
DC Power Plant Size	Amperage			
DC Power Plant Load	Amperage			
DC Power Plant Battery Amp Hours	Amp Hours			
UPS Size	Kilowatts			
UPS Output Load	Kilowatts			

Key Metric	Measurement Unit	Green	Yellow	Red
Inverters		<60%	60- 80%	>80%
Inverter Size	240V Single Phase Kilowatts			
	120V Single Phase Kilowatts			
	120/208V 3Three Phase Kilowatts			
Inverter Load	Amperage			
HVAC		<60%	60- 80%	>80%
Total Tons Building HVAC	Tons BTU			
Total Tons Headend HVAC	Tons BTU			
Floor Space & Monitoring				
Available Floor Space	Rack locations			
Video monitoring system installed	Judgement			
Site Cleanliness	Judgement			

An example of the technical facilities scorecard is shown on figure 5. As presented, both sites 5 and 13 have space issues. Site 6 has saturated commercial power based on its peak load, and site 15 needs a bigger generator because equipment deployed have outgrown the existing generator capacity. The overall technical facility system score is 89 and the health of the system is coded yellow, suggesting caution.

TECHNICAL FACILITIES SCORE CARD **Oct-yy**

Facility	Tier	HVAC	Power	Gen	DC Plant	Battery	UPS/Inv	Space	Monitoring	Cleanliness	Fire Supp	Score
Site 1	1											46
Site 2	1											43
Site 3	1											46
Site 4	1											48
Site 5	1											39
Site 6	1											43
Site 7	1											50
Site 8	1											42
Site 9	1											46
Site 10	1											46
Site 11	1											50
Site 12	1											46
Site 13	1											35
Site 14	1											42
Site 15	1											44
									Tier 1 Totals			44.4
Site 16	2											30
Site 17	2											30
Site 18	2											30
Site 19	2											27
Site 20	2											28
Site 21	2											28
Site 22	2											30
Site 23	2											26
Site 24	2											27
Site 25	2											28
Site 26	2											27

… List Truncated …

Total Score
89.95

Figure 5 - The Technical Facilities Scorecard

2. Data Network Scoring System

To score the data network, the most critical links were first identified. These are aggregation links carrying customer and service traffic. Examples of such links include the connections between the RDC and the MTC or leased circuits for redundant Internet connectivity. These links, also known as interconnects, were grouped by type (backbone, leased, spur, ring) and their utilizations were individually reported based on the utilization report from Tivoli Netcool Performance Manager (TNPM).

An interconnect is considered green if its utilization ratio is less than 60 percent of its capacity at the 95th percentile. All interconnects being protected on an east-west path, this allows for the support of most traffic on one side in the event of a failure of the other path. Interconnects are marked yellow if their utilization ratio is between 60% and 75% at the 95th percentile while those with utilization above 75% are marked red.

On the final data scorecard, green interconnects add 100% of their weighted value based on the number of interconnects in the category or type. Yellow interconnects add 50% of their weighted score and red interconnects add nothing. The sum of all these scores results in a total score showing the health of the data network. A total score above 95% is green; between 80% and 95% is yellow; and less than 80% is red. The total score is then standardized and reported on the system scorecard for the data network.

Figure 6 shows an example of a data scorecard resulting from sub-scorecards of selected links. In this representation, none of the data links is red which means the data network is in a healthy state, scoring 97.96 over 100 possible points.

DATA SCORECARD **Oct-yy**

	Total Interconnects	Green	Yellow	Red
RDC Backbone	10	10		
Leased Circuits	4	2	2	
Spurs	9	8	1	
East K Ring	43	43		
West K Ring	27	27		
Metro Ring A	17	17		
Metro Ring O	37	34	3	
Total	**147**	**141**	**6**	**0**
Percentage	**100%**	**95.92%**	**4.08%**	**0.00%**

Monthly Score to Report	**97.96**

Legend

Green interconnects add 100%
Yellow interconnects add 50%
Red interconnects add 0%

Figure 6 -The Data Network Scorecard

3. Transport Network Scoring System

The principle of the transport network scorecard is similar to that of the data network scorecard but instead of Ethernet links, the transport scorecard identifies lambdas, STS', and cross-connects of importance as explained in the previous section related to the transport network. For the first category, all lambda routes are listed and their utilization scored. A lambda or wavelength is considered utilized once it is allocated for a specific purpose. For example, a 10G lambda can be allocated to carry data traffic between the MTC and the RDC.

A lambda route is red if its utilization is above 75% of capacity. The capacity of a lambda route is the total number of equipped lambdas on that route. The lambda route is yellow if its utilization is between 60% and 75% and green if its utilization is below 60%. All the lambdas in the transport network are currently configured in a ring topology to allow redundancy.

Just like lambdas, STS' are organized in rings. Each STS ring is listed under its master ring name along with the STS' name and characteristics (e.g. OC-48, 2xOC48, OC-192). A ring listed as 2xOC-48 suggests that a second OCx48 was activated on that same ring with the same parameters as the first. Each STS ring is scored green, yellow, or red using the same utilization criteria like the lambda (<60%, 60-75%, >75%) and the total number of green, yellow and red STS rings is reported on the scorecard.

The third category on the transport scorecard is the cross-connects report. Cross-connects were a major source of failed or delayed projects due to chassis constraints and lead time to acquire and deploy new cross-connect cards such as the Cisco XC, XCVT, XC10G, or XC-VXC cards. For that reason, including them on the scorecard was deemed a proactive measure for improving customer experience by increasing on-time delivery of new services. As such, cross-connect report was added to the transport scorecard to identify shortcomings and take proactive action. This sub-scorecard identifies every transport network element (NE) or chassis with cross-connect capability and lists the percentage of VT1.5 and STS-1 consumed in the chassis. Using the same scale like the previous categories, each NE's VT1.5 and STS-1 are scored green, yellow, or red. Any red score makes the chassis red. If both VTs and STS' are green, the chassis is green else, the chassis is yellow. The result of this sub-scorecard is reported in the transport scorecard as a sum of chassis and a sum of each color. For the final score, any green or yellow percentage score increases the total score while a red percentage score reduces the final score.

The overall transport network score is obtained by adding the scores for lambda, STS, and cross-connects as shown on figure 7. If the final score is 90 or more, the transport network is green. A score below 90 but greater or equal to 75 makes the system yellow. A score below 75 makes the system red.

TRANSPORT SCORECARD **Oct-yy**

	Region-K	Region-A	Region-O	Total	Score
Lambda					
Total Lambda routes	8.00	3.00	4.00	**15.00**	
Green	7.00	2.00	3.00	**12.00**	
Yellow	1.00	0.00	0.00	**1.00**	
Red	0.00	1.00	1.00	**2.00**	**0.87**
STS					
Number of STS Rings	37.00	19.00	13.00	**69.00**	
Green	29.00	11.00	8.00	**48.00**	
Yellow	2.00	2.00	4.00	**8.00**	
Red	6.00	6.00	1.00	**13.00**	**0.81**
Cross-Connects					
Total shelves	67.00	8.00	25.00	**100.00**	
Green shelves	60.00	8.00	24.00	**92.00**	
Yellow shelves	4.00	0.00	1.00	**5.00**	
Red shelves	3.00	0.00	0.00	**3.00**	**0.97**

Monthly Score to Report	**88.28**

Legend

Green lambda, STS, or crossconnects maintains score
Yellow lambda, STS, or crossconnects maintains score
Red lambda, STS, or crossconnects reduces score

Figure 7- The Transport Network Scorecard

4. DOCSIS Network Scoring System

The basis of the DOCSIS or CMTS scorecard is the weekly average utilization report of all radio frequency (RF) signals or carriers allocated to this network in general and to Internet in particular. Indeed, signals related to the DOCSIS set-top gateway (DSG) for set-top out-of-band communication, telemetry, and management are not taken into account in this scorecard. The list of DOCSIS carriers (RF signals allocated to DOCSIS) is grouped by serving group (SG) also called service group, representing the group of nodes served by a group of RF signals on the upstream or on the downstream. The upstream and downstream scores are calculated separately using a common principle. Each carrier is considered over-utilized if its utilization at the 95th percentile is 70% or above. Based on this report, a SG is made red if any one of its carriers is over utilized. The list of red SGs will later be used during the analysis to address any pending issue on the network.

Because a SG resides on one CMTS as two CMTS' do not serve the same node, the CMTS is cored based on the ratio of red SG compared to the total number of SG it contains. A CMTS chassis is green if less than 5% of its carriers are over-utilized; it is yellow if the ratio of over-utilized carriers is between 5 and 10%, and red if it is greater than 10%. This view helps identify chassis creating the most pain on the network. At the system level, a market or region will be green if less than 5% of its carriers are over-utilized; yellow if over-utilized carriers are between 5 and 10%, and red if overutilization is above 10%. The overall system score is the average of the upstream and downstream system scores as presented on figure 8.

DOCSIS CAPACITY SCORECARD

Location	Week-1	Week-2	Week-3	Week-4
Region A	92.26%	91.74%	94.79%	94.76%
Region K	97.01%	96.78%	97.22%	97.70%
Region O	96.95%	97.48%	98.19%	98.04%
Region S	98.32%	92.26%	100.00%	98.92%
Total	**96.52%**	**96.38%**	**97.19%**	**97.32%**

MONTHLY **96.85%** **STD SCORE** **93.70**

Downstream Carriers	
Location	**Count**
Region A	1265
Region K	4664
Region O	3259
Region S	104
Central	**9292**

Upstream Carriers	
Location	**Count**
Region A	741
Region K	2102
Region O	2761
Region S	84
Central	**5688**

KEY:
< 5% of Total Carriers are Over Utilized
< 10% of Total Carriers are Over Utilized
>= 10% of Total Carriers are Over Utilized

Figure 8 - The DOCSIS Network Scorecard

5. Video Network Scoring System

The video capacity scorecard includes scores related to the VOD and SDV service group utilization. The VOD successful sessions and SDV tune-in success rate are part of the video reliability scorecard and will not be addressed in this article. To create the VOD and SDV capacity scorecards, the list of respective SGs is generated using the respective element management systems (EMS), along with the average peak utilization for the selected period based on a 15 minute-interval. This calculation is based on the total bandwidth available for the SG, knowing that a VOD or SDV AQM is 38.8 Mbps. As such, a SG with 4 QAMs is 155 Mbps, one with 5 QAMs is 194 Mbps, and one with 8 QAMs is 310 Mbps.

A SG is marked over-utilized if its average peak utilization is greater than 75% for SDV or 85% for VOD. The difference in the maximum utilization ratio derives from the manufacturer recommendation. Indeed, 75% is the threshold recommended by the SDV solution provider. It is the limit at which additional QAMs or new SGs are required to maintain a good customer experience. The final SDV and VOD scores are calculated for each region using the formula:

$$1 - \frac{Total\ Over\ Utilized\ SG}{Total\ SG}$$

The system score is calculated the same way using overall system values. An example of the video scorecard is presented on figure 9. Any market or system score above 95% is marked green; a score between 90 and 95% is marked yellow, while any score below 90% is considered red. The final system score is standardized and reported on the overall system capacity scorecard for the given period.

VIDEO (VOD & SDV) CAPACITY SCORECARD

SDV Service Groups with Utilization above 75%

Location	September-yy		October-yy	
	Total SG	SG >75%	Total SG	SG >75%
Region A	296	4	320	9

SDV Service Group Utilization Performance

Location	September	October	Variance
Region A	98.65%	97.19%	**-1.46%**

VOD Service Groups with Peak Utilization Greater than 85%

Location	September-yy		October-yy	
	Total SG	SG >85%	Total SG	SG >85%
Region A	320	9	320	0
Region K	353	69	388	82
Region O	208	10	298	9
Region S	16	0	16	0
Central Region	**897**	**88**	**1022**	**91**

VOD Service Group Utilization Performance

(Percentage of SG under the 85% threshold for the reporting period.)

Location	August	September	October	Variance
Region A	94.93%	97.19%	100.00%	**2.81%**
Region K	80.00%	80.45%	78.87%	**-1.59%**
Region O	85.10%	95.19%	96.98%	**1.79%**
Region S	100.00%	100.00%	100.00%	**0.00%**
All Regions	86.71%	90.19%	91.10%	**0.91%**

Total Utilization Performance for the Month	**91.10%**

Normalized Score to Report for the month	**82.19**

Green	95% to 100% VOD Service Group Utilization Performance
Yellow	90% to 95% VOD Service Group Utilization Performance
Red	<90% VOD Service Group Utilization Performance

Figure 9 - The Video Network Scorecard

6. Telephony Network Scoring System

The telephone scorecard is based on metrics identified as determinants of the telephone network capacity. These metrics include SPM port availability, IWSPM peak utilization, CS2K end point capacity, TVCID AIN triggers, SIP SOC RTU peak utilization, trunk side GWC BHCA utilization, line side GWC BHCA utilization, DS1 capacity on gateways, and STS available on DACS. Information on availability is based on utilization. For example, if 25% of ports are utilized, then 75% of ports are available.

The telephone scorecard is organized in four main categories namely (1) DMS/CS2K; (2) Gateway controller utilization; (3) Nuera 4K/8K Gateways; and (4) DACS. All categories are weighted the same, each contributing at 25% of the total telephony score. Each category contains a set of weighted key metrics as shown of table 4. The weight of a metric in a category is determined by its potential impact to customers in case of saturation. An example of the telephony scorecard is presented on figure 10.

Table 4 - Telephony Scoring Grid

Category / Metric	Metric Weight	Category Weight
DMS/CS2K		*25%*
SPM Port Availability	20%	
IWSPM Utilization Peak	10%	
CS2K End Point Only Capacity	30%	
TVCID AIN Triggers	10%	
SIP RTU SOC Peak Utilization	30%	
Category Totals	100%	
Gateway Controller Utilization		*25%*
Trunk Side GWC BHCA Utilization Only	60%	
Line Side GWC BHCA Utilization Only	40%	
Category Totals	100%	
Nuera 4K/8K Gateway		*25%*
DS1 Capacity Market-W	40%	
DS1 Capacity Market-J	30%	
DS1 Capacity Market-F	30%	
Category Totals	100%	
DACS		*25%*
5500 STS Available	70%	
532 Ports Available	30%	
Category Totals	100%	
OVERALL SCORE		*100%*

TELEPHONY CAPACITY SCORECARD

Key Telephony Metrics (Region-K)	Aug-yy	Sept-yy	Oct-yy
DMS/CS2K			
SPM Port Availability	4	4	4
IWSPM Utilization Peak	25.72%	25.66%	25.78%
CS2K End Point Capacity	82.28%	81.59%	80.41%
TVCID AIN Triggers	73.27%	73.09%	72.40%
SIP SOC RTU Peak Utilization	50.95%	52.51%	83.35%
Category Totals	**60.00%**	**60.00%**	**37.50%**
Gateway Controller Utilization			
Trunk Side GWC BHCA Utilization Only	9.39%	9.44%	9.33%
Line Side GWC BHCA Utilization Only	27.25%	27.14%	27.44%
Category Totals	**100.00%**	**100.00%**	**100.00%**
Nuera 4K Gateway			
DS1 Capacity Market W	63.69%	65.20%	65.20%
DS1 Capacity Market J	85.11%	85.11%	85.11%
DS1 Capacity Market F	48.21%	48.21%	48.21%
Category Totals	**77.50%**	**77.50%**	**77.50%**
DACS			
5500 STS Available	32	31	32
532 Ports Available	36	36	39
Category Totals	**82.50%**	**82.50%**	**82.50%**
Total Score Region-K	**80%**	**80%**	**74%**

Key Telephony Metrics (Region-O)	Aug-yy	Sept-yy	Oct-yy
… Scorecard Truncated …			
Total Score Region-O	**83%**	**83%**	**83%**
TELEPHONY SYSTEM SCORE	**81%**	**81%**	**78%**

Overall Scoring System
Green: 95% to 100%
Yellow: 80% to 95%
Red: Below 80%

Figure 10 - The Telephone Network Scorecard

7. RF Spectrum Scoring System

The objective of RF management is to ensure the availability of this limited resource for the deployment of new programs or services. For example, if an operator wants to add additional downstream DOCSIS bandwidth, that will need to come from the current RF spectrum. To this effect, the RF spectrum scorecard takes into account the existing channels on the spectrum, looks at the planned gains and needs for a period, then computes the number of channels available by the end of the period. For this scorecard to be effective, regular collaboration with boundary partners in charge of equipment or programming that need spectrum is required. Such boundary partners include video engineering, DOCSIS engineering, telephony engineering, product, marketing, as well as government and public affairs departments.

The spectrum scorecard considers each market or spectrum boundary, looks at the total number of subscribers served in the market, then creates a weight that is equivalent to the proportion of subscribers. Based on the spectrum needed by market, the total spectrum capacity remaining by the end of the period is calculated. If the number of RF channels remaining at the end of the period is positive, the market is green and scores its weight. If this number is negative, the market is red, scoring a quarter of its weight. If it is zero, the market is yellow, scoring ¾ of its weight. The total system score is the sum of all the market scores. It is green if above 95%, red if below 90%, and yellow if between 90% and 95%. This score is later standardized using the system's normalization algorithm and reported in the system scorecard. Figure 11 shows an example of RF spectrum scorecard.

RF SPECTRUM SCORE CARD **Oct-yy**

Downstream Spectrum Allocation *(expressed in 6 MHz carriers)*

QAM CATEGORY	Market 1	Market 2	Market 3	Market 4	… Truncated …	Market 11	Market 12	Market 13	Market 14	Market 15
Analog Carriers	59	62	62	58		59	58	59	57	60
SD Carriers	12.8	11.7	11.1	11.3		24	23	23.2	23.8	24.2
HD Carriers	32.5	33.5	34	33.5		38.5	40.5	39.5	39	42
3D Carriers	0.5	0.5	0.5	0.5		0.5	0.5	0.5	0.5	0.5
VOD Carriers	5	5	5	5		4	4	4	4	8
SDV Carriers	8	8	8	8		0	0	0	0	0
DOCSIS	8	8	8	8		5	8	8	8	8
Circuit Switched Telephone	0	0	0	0		0	0	0	1	1
Control/Signaling	1	1	1	1		1	1	1	1	3
Unusable	0	0	0	0		0	0	0	0	0
Current QAMs Used/Unusable	126.8	129.7	129.6	125.3		132	135	135.2	134.3	146.7
Max QAMs	134	134	134	134		152	152	152	152	153
Current Unused QAM capacity	7.2	4.3	4.4	8.7		20	17	16.8	17.7	6.3
Planned Spectrum Usage	-1.5	-1.5	-1.5	-1.5		-9.5	-6.5	-7.6	-6.5	-4
Planned Spectrum Gains	1	1	1	1		3	3	3	3	1
Surplus/Deficit QAM Capacity	6.7	3.8	3.9	8.2		13.5	13.5	12.2	14.2	3.3

	Market 1	Market 2	Market 3	Market 4	… Truncated …	Market 11	Market 12	Market 13	Market 14	Market 15	Total
Subs served											
Weight	3%	1%	6%	1%		2%	3%	7%	22%	34%	100%
Downstream Score	3%	1%	6%	1%		2%	3%	7%	22%	34%	**100%**

Upstream Spectrum Allocation *(expressed in 1 MHz carriers)*

	Market 1	Market 2	Market 3	Market 4	… Truncated …	Market 11	Market 12	Market 13	Market 14	Market 15	Total
Status Monitoring	0.3	0.3	0.3	0.3		0.3	0.3	0.3	0.3	0.496	
Sweep Return	0.8	0.8	0.8	0.8		0.8	0.8	0.8	0.6	0.9	
Digital Box Return	0.384	0.384	0.384	0.384		0.192	0.192	0.192	0.192	0.384	
Circuit Switched Telephone	0	0	0	0		0	0	0	5.632	14.636	
CHSI Return	9.6	9.6	9.6	9.6		9.6	19.2	19.2	9.6	16	
Upstream Spectrum Usage	11.084	11.084	11.084	11.084		10.892	20.492	20.492	16.324	32.416	
Max Upsteam Bandwidth (MHz)	37	37	37	37		37	37	37	37	35	
Available Upstream Bandwidth (MHz)	**25.916**	**25.916**	**25.916**	**25.916**		**26.108**	**16.508**	**16.508**	**20.676**	**2.584**	
Upstream Spectrum EOY Planned Need	0	0	0	0		0	0	0	0	0	
Upstream Spectrum EOY Planned Gain	0	0	0	0		0	0	0	0	0	
Surplus/Deficit Upstream Capacity	25.916	25.916	25.916	25.916		26.108	16.508	16.508	20.676	2.584	
Upstream Score	3%	1%	6%	1%		2%	3%	7%	22%	34%	**100%**

Figure 11 - The RF Spectrum Scorecard

8. The System Capacity Scorecard

The system capacity scorecard standardizes individual scorecards previously presented to an overall system view. According to the online version of Oxford Dictionary, a standard is something used as norm or model for comparative evaluations and standardization consists of making something conform to an established standard (Oxford University Press, 2017). For the overall system scorecard, a standard was created and helped transcribe scores from individual scorecards that use different grading systems to the established standard. In the standard scorecard, a green score or healthy sub-system is graded between 90 and 100. A yellow sub-system is graded between 80 and 90, and a red sub-system is graded below 80. A representation of the score converter is shown in figure 12. The scale of the subsystem scorecard is stored in the column labelled "From", and that of the system scorecard is stored in the column labelled "To". The subsystem's score is entered in the "Current Score" and automatically computes the "Score to Report". Figure 13 shows a view of the system scorecard corresponding to a standardized summary of each of the scorecards presented previously along with a trend line representing the evolution of the scores for the previous three months.

Video

Current Score 94.50 ➔ **Score to Report 89.00**

	From	To	Score
Green Max	100.000	100	
Green Min	95.000	90	
Green Increment	0.00500	0.01000	
Yellow Max	95.000	90	
Yellow Min	90.000	80	**89.00**
Yellow Increment	0.00500	0.01	
Red Max	90.000	80	
Red Min	0.000	0	
Red Increment	0.09000	0.08	

Figure 12 - Score Standardization

SYSTEM CAPACITY SCORECARD

CAPACITY SCORECARDS	Weight	Owner	Jul-yy	Aug-yy	Sept-yy	Oct-yy	Trend
DATA	15%	Data Engineer	97.96	98.98	98.98	97.96	
TRANSPORT	15%	Transport Engineer	87.61	88.28	88.28	88.28	
CMTS	15%	CMTS Engineer	86.38	83.13	91.59	93.70	
FACILITIES	15%	Technical Facilities Eng.	89.52	89.47	89.95	89.95	
RF SPECTRUM	15%	Video Engineer	100.00	100.00	100.00	100.00	
VIDEO (VOD, SDV)	15%	Video Engineer	77.24	78.71	80.38	82.19	
TELEPHONY	10%	Telephone Engineer	80.21	80.83	80.83	78.44	
SYSTEM CAPACITY TOTAL			**88.83**	**88.87**	**90.46**	**90.66**	

Green	Between 90 and 100
Yellow	Between 80 and 90
Red	Less than 80

Figure 13 - The System Scorecard

5. Analysis and Troubleshooting

The standardized system scorecard serves as a levelling tool in representing all scorecards using a common metric. By itself, it helps understand the evolution of the network capacity over the months and identify areas of concern. For example, a category that consistently stays red or one that suddenly becomes yellow or red such as telephony in figure 13 calls for explanations. For that reason, there is a process to share the findings of the scorecard in a meeting setting.

On a monthly basis, the Network Operations leaders and boundary partners meet for a presentation of the network's health. To make the meeting interesting to everyone, leaders of the different networks are also owners of their respective scorecard findings and action items, even though the scorecards are created by engineers in the planning team. The presentation of the scorecards is done in the form of analysis structured around three main points:

- Month to month performance comparison and improvements implemented
- Areas of concern and lessons learned
- Plan to stay or become green (projects to kick off, processes to change, etc.)

The structure presented above helps organize discussions and provides guidance to properly analyze the findings of the scorecards. Regardless of the system's color, each red item in the subtending scorecard needs to be identified, understood, and resolved in order to make the system become or stay green. For that same reason, items marked yellow should be discussed and monitored.

When an issue of interest is identified, the planning engineer creates trouble tickets and assigns them to a subject matter expert (SME) or a person selected by the technology owner. The technology owner is responsible for following the tickets to resolution with help from the planning engineer, and reports from the trouble tickets are shared with the teams during various project and team meetings.

8. Areas of Further Investigation

While the deployment of a standardized scorecard allows the operator to be proactive and resolve issues prior to customer complaints, its efficiency depends on the identification of the correct metrics and follow-up of issues to their complete resolution. In other words, time is spent solving a problem that is not yet real to the end users and the company needs to identify and assign appropriate resources to undertake such tasks.

Even though the scorecard presented here obtains all its data from automated sources, the individual scorecards are compiled using Microsoft Excel. This is time consuming and provides an opportunity for improvement. The main issue faced with such opportunity is the vast number of platforms to query and assemble data. Indeed, all the subtending scorecards collect data from different sources requiring different types of expertise.

In addition to automation, the scorecard needs to be adapted for new technologies. For example, the deployment of DOCSIS 3.1, fiber deep, and remote PHY would create various levels of complexity due to the number, size, and structure of service groups. Further research needs to be conducted to confirm this assertion.

To make the standardize scorecard system more efficient, there needs to be a correlation between the improvement seen on the scorecards and customer experience measured in terms of number and types of trouble tickets, Net Promoter Score (NPS), or customer satisfaction as discussed by Lartey, Hargiss, and Howard (2015).

Conclusion

This paper presented a method for monitoring an entire broadband or telecommunications network using standardized scorecards. The main objective in doing so is to proactively resolve network issues prior to negative customer experience. In doing so, the paper first presented a literature review on measurement theory, followed by an overview of the broadband network. The overview resulted in the identification of key performance metrics in each of the broadband networks and critical infrastructures. These networks and infrastructures included technical facilities, data network, transport network, DOCSIS network, video network, telephony network, and RF spectrum. After presenting the rationale for the selection of the key metrics on each network, the paper presented detailed procedures on how to create the respective scorecards, along with real example of each of the scorecards. Finally, the paper presented an operational analysis and troubleshooting process before ending with a discussion on areas of further investigation.

Regardless of the level of automation, human intervention is always required to analyze issues and implement corrective measures or else, existing issues can become chronic problems defined by Sasisekharan, Seshadri, and Weiss (1994) as “problems that are likely to continue in the immediate future without diagnosis and repair" (p. 453). Indeed, leaving little issues unresolved will certainly result in bigger issues in the future. To keep networks at peak performance, humans need to understand their current state and take action for their future evolution.

Abbreviations

AC	alternating current
AIN	advanced intelligent network
AP	access point
BHCA	busy hour call attempts
bps	bits per second
CCAP	converged cable access platform
CMTS	cable modem termination system
CS2K	CallServer 2000
DACS	digital cross-connect system
DC	direct current
DCS	digital cross-connect system
DMS	digital multiplex system
DOCSIS	data over network system interface specification
DSG	DOCSIS set-top gateway
DVR	digital video recording
DWDM	dense wavelength division multiplexing
EMS	element management system
FEC	forward error correction
GHz	gigahertz
GWC	gateway controller
HD	high definition
HFC	hybrid fiber-coax
HVAC	heating, ventilation, and air conditioning
Hz	hertz
IPTV	Internet protocol television
ISBE	International Society of Broadband Experts
ISP	inside plant
IWSPM	interworking spectrum peripheral module
KHz	kilohertz
KPI	key performance indicator
MHz	mega hertz
MSO	multiservice operator
MSSP	multiservice switching platform
MTC	master telecommunications center
NE	network element
NPS	net promoter score
nPVR	network-based personal video recorder
OC	optical carrier

ONE	optical network element
OSP	outside plant
RDC	regional data center
RF	radio frequency
ROADM	reconfigurable optical add drop multiplexer
RTU	right-to-use
SCTE	Society of Cable Telecommunications Engineers
SDH	synchronous digital hierarchy
SDV	switched digital video
SG	service group or serving group
SIP	session initiation protocol
SME	subject matter expert
SOC	software optionality control
SONET	synchronous optical network
SPM	spectrum peripheral module
STB	set-top box
STC	secondary telecommunications center
STS	synchronous transport signal
TBSCT	telecommunication building critical system tool
TDM	time division multiplexing
TNPM	Tivoli Netcool Performance Manager
TVCID	television caller identification
UPS	uninterruptible power source
VOD	video on demand

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