BENCHMARKING SYSTEM OPERATION PROCESSES FOR 22 INTERNATIONAL TRANSMISSION SYSTEM OPERATORS

BART FRANKEN* (KEMA), LAITH AHMED ALBASSAM (SAUDI ELECTRICITY COMPANY), CM MAK (CLP HONG KONG), ALBERT DICAPRIO (PJM), OLIVER SCHEUFELD (KEMA)

Summary: *Following the liberalization of electricity markets in many parts of the world, Transmission System Operators (TSOs) are facing entirely new challenges in operating their systems. Liberalized electricity markets created a desire to learn from other international TSOs and in 1995 the TSO Comparison group was formed. Today, a database with TSO System Data and Performance Measures is available for the twenty-two members of the group. This database includes over 50 selected performance indicators of the member TSOs. Using these performance measures, detailed multi-dimensional Benchmarking Studies are carried out.*

This paper describes Benchmark Models for the main System Operation processes: Real Time, Operations Planning, Scheduling and After the Fact. These benchmarking models use the most significant cost-drivers for the individual processes, including system complexity indicators (number of circuit ends, number of generators and number of interconnectors) and system activity indicators (number of scheduled outages, number of unplanned outages, foreseen transmission concern).

The development of a benchmark model for the Support Process is also described in this paper. The support process consists of all activities supporting the other four activities, such as training, IT system maintenance, SCADA systems, software development, Electronic Data Interchange. The benchmark model for Support takes into account both the use of staff (FTEs) and cost.

The authors would like to thank the representatives of all 22 TSOs (see section 7) for their contributions.

Keywords: *Benchmarking, Transmission System Operators, Dispatching, Real Time Operation, Scheduling, Operations Planning.*

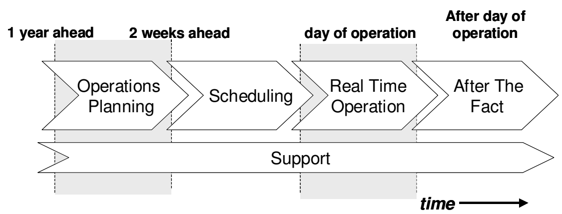
Introduction

The international TSO Comparison Group is a group of electrical Transmission System Operators (TSOs) spanning Asia, Europe, Africa, Middle East, South Pacific and North and South America and was formed in 1995. Its mission is to exchange information on current and future System Operation practices for the purpose of benchmarking. Members of the TSO Comparison Group meet regularly and exchange information in workshops, conference calls, by email and via their website www.tso-comparison.com.

The TSO Comparison Group focuses on System Operation activities which are usually concentrated in or close to the Control Center and include load/generation balancing, ancillary services and network operation tasks. Moreover, since the liberalization of power markets, both the influence of power markets and markets run by TSOs are increasingly important. The group's focus is on the period from approximately one year ahead, including all activities up to after the day of operation. This time scale is divided into four different key processes and one support process, which are shown in FIGURE 1.

Bart Franken is Senior Consultant Markets and Regulation at KEMA. Please contact him for more information on the TSO Comparison project, bart.franken@kema.com. KEMA's Corporate Head office is based in the Netherlands (regional office in Dubai, Dubai@kema.com).

FIGURE 1: THE FIVE PROCESSES OF A TSO AS DEFINED BY TSO COMPARISON GROUP



During recent years, the TSO Comparison Group has developed several useful tools that support its mission. Firstly, a set of performance measures was defined for TSOs. This set of over 50 measures has been collected annually since 2000 and is stored in the **Performance Measures database**. Currently, the 2000-2007 database forms a valuable asset for benchmarking models developed in the TSO Comparison Group. Furthermore, because this database is disclosed to all members of the TSO Comparison Group, it is often used for answering questions from individual TSOs[1].

Building on this Performance Measures database, the TSO Comparison Group has developed five statistical **Benchmark Models** in which the System Operation processes of FIGURE 1 are compared amongst the TSOs. These multi-dimensional Benchmark models compare the use of resources (staff and costs) of different TSOs, taking into account the size of their system and the amount of their activities[2].

Although the benchmark models take some environmental factors into consideration, power systems and the organization of the power sector differs significantly amongst the member countries. In order to better understand these differences, the TSO Comparison group uses **Key Activity Matrices**. These matrices provide background information on the activities which are performed by the 22 TSOs in their different time scales and intensity.

Results of benchmark models and key activity matrices are used for the identification of out-performers on the different processes. These out-performers **present their practices** on this process in more detail during workshops of the TSO Comparison Group, which enables both learning from best practice and improvement of existing benchmark models.

Recently, the TSO Comparison Group has developed a **key graph** which serves as an executive summary of the benchmark results. This single slide summary provides an overview of both use of 'resources' and the performance of the member TSOs.

This paper provides an overview of the tools and methodologies developed by the TSO Comparison Group. In chapter 2, we firstly define the different processes that are considered in this project and detail them with results from the key activity lists. We then describe in chapter 3 the collection of performance measures. In chapter 4 we explain the benchmark models for the different processes in more detail. In chapter 5, we discuss the recently developed key graph.

2 Five Processes of a Transmission System Operator

FIGURE 1 shows the five different processes within System Operation, which define the work of the TSO as considered in this study. In practice however, none of the TSOs are organized exactly like this TSO. Moreover, many TSOs consider more (or less) activities as part of system operation. However, when applying a benchmark model to system operation processes, one should make sure that the activities are made comparable. Therefore, the TSO Comparison Group has taken a major effort to understand the differences between the TSOs. This has resulted in a description of 'standard' activities of a TSO and key activity matrices in which TSOs have indicated the intensity of the major activities of the process. In this section we describe the five processes which are found in a great variety of different forms all over the world.

2.1 Operations Planning

Operations Planning is the planning cycle that plans outages from roughly **one year up to two weeks ahead**. This includes co-ordination and planning outages of generators and transmission, announced by Transmission Asset Owners (or Asset Management Department of a TSO) and Generator owners. The result is a plan that is one of the inputs of the Scheduling process. This plan may be adjusted throughout the operations planning period.

The objective of the Operations Planning process is to produce accurate and timely plans for the Scheduling and Real Time Operation processes. The Operations Planning process aims to guarantee system security and market capacity needed in the Operations Planning timeframe.

[1] Data is exchanged openly within the group, but kept strictly confidential. This enables open and fair comparison and prevents strategic provision of Performance Measure data.

[2] The background of the multi-dimensional Benchmark models is described in a previous paper of the TSO Comparison Group [1].

TABLE 1:Core Activities of the Operations Planning process

Task Description		Activity level: Not done	Receive	Forecast	Determine
Transmission network assessment	Outage management			2 TSOs	18 TSOs
	Network capability	1 TSO	2 TSOs	6 TSOs	11 TSOs
	Contingency planning	2 TSOs	1 TSO	1 TSO	16 TSOs
	Switching programmes	5 TSOs			15 TSOs
	Interconnector transfers	3 TSOs		3 TSOs	14 TSOs
	Emergency preparedness		1 TSO	1 TSO	18 TSOs
Energy assessment	Demand forecast	3 TSOs	1 TSO	5 TSOs	11 TSOs
	Generation schedule	5 TSOs	1 TSO	5 TSOs	9 TSOs
	Hydro management	7 TSOs	2 TSOs	2 TSOs	9 TSOs
	Manage transmission losses	5 TSOs			15 TSOs
Ancillary Services (AS) management	AS requirement	6 TSOs		3 TSOs	11 TSOs
	AS procurement	4 TSOs			16 TSOs

Although there is consensus within the TSO Comparison Group about the general functional description of the Operations Planning Process, the intensity of activities performed is different for each TSO. Using 'Activity Lists', the member TSOs indicated which activities are performed by the TSOs. In addition the intensity of each activity is demonstrated. The results for the Operations Planning process are shown in TABLE 1. Even if such an activity list is not an input-factor for the benchmarking process itself, it is nevertheless valuable to understand the results and to recognize peer groups.

2.2 Scheduling

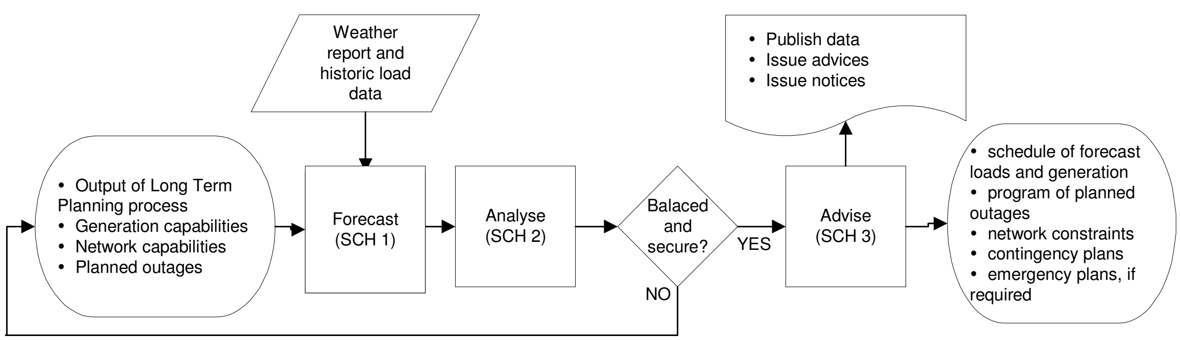
Scheduling is the short-term planning cycle to prepare for real time operation. One of the inputs is the outage plan resulting from the Operations Planning process. The scheduling cycle is carried out **between 2 weeks and 1-day ahead** of operation.

The objective of the process 'Scheduling' is to prepare an accurate schedule of generating unit dispatch targets to meet the forecasted demand, without violating the planned network capability, by delivering a *balanced* and *secure* power system to the Real Time Operation process.

The Scheduling process comprises of three sub-processes (see FIGURE 2): Forecasting, Analysing and Advising. In accordance with operating procedures, the scheduling staff forecast the estimated demand and collect the corresponding schedules of generating unit output levels. The schedules are analysed to confirm that an energy balance is achieved with adequate capacity reserve and network analysis is carried out to confirm that the power system, with the outages as planned, would remain secure following a credible contingency event. The schedule should be revised, where necessary, until these conditions are achieved.

When the schedule of forecast loads and generation is completed, information should be provided to the

FIGURE 2: SIMPLIFIED PROCESS MODEL OF "SCHEDULING"



appropriate parties. This information includes: schedules, advice, notifications, plans and data.

Similar to TABLE 2, an Activity overview is also prepared for the Scheduling process. All TSOs include Transmission Network Assessment activities in their Scheduling process, while for the Energy Assessment activity only Demand Forecast is performed by a number of TSOs. Generation Scheduling is generally not handled by this process. Regarding Ancillary Service Management, some TSOs handle them (determine requirements, procure) in the Operations Planning process, some TSOs as part of the Scheduling process and at some TSOs they are considered to be part of both the Scheduling and the Operations Planning process.

2.3 Real Time Operation

Real Time Operation covers all activities required to operate the transmission system (e.g. supervision, keeping energy in balance and switching if applicable). These activities are usually performed in the Control Room of the TSO.

The **main objectives** of the Real Time Operation process are to ensure that real time energy and power are balanced and network security is maintained under normal and emergency conditions. An additional objective is to minimise cost through economic dispatch and to minimise network losses[3].

The process inputs to Real Time Operation are:

- *Operation rules and guidelines.* i.e. internal rules and guidelines defined for operators in order to organize the work in a standardized and secure way, and maintain the system balance and the security of the system within predefined limits;
- *Output of Scheduling process:* For example network and generation maintenance plans, generation schedule, special event plans etc.;
- *Real time information:* Information (status, analogue measurements and alarm signals) monitored by the real time on-line system presented to the real time operators; and
- *Telephone calls, faxes etc.:* Other communications to the real time operators by other parties via telephone, fax, radio, etc.

The main actors in this process are the control room operators. They monitor the status and performance of the power system by interpreting the information (sub-process 'Monitoring'), presented to them by:

- *their computer systems:* for example frequency, load on (tie) lines, energy balance, Power and Reactive Power generation of different plants, network topology, results of real time contingency analysis, voltages etc.; and
- *other media such as telephone, fax:* e.g. requests from Transco's for assistance in solving their network constraints, requests from maintenance crews to de-energize components, information about faulty components etc.

The interpretation of information is based on operation rules, operator experience and information from the scheduling process. The result of this monitoring is either 'The system-security will be within the predefined limits' or 'It is not clear if the system will be within the predefined limits and analysis of the current situation is therefore necessary'.

In this last instance, a sub-process 'Analysis' will be triggered. The objective of this sub-process is to define actions that have to be taken to maintain or restore a secure system. The operator analyses the current situation in detail, defines measures to be taken and checks the consequences of these measures. The result of this sub-process is the definition of the actions to be taken.

These actions are the input for the next sub-process of 'Control'. The objective of the sub-process of control is to translate the actions required into instructions for Generators, Loads and network operators. These instructions are clearly defined tasks, such as increasing reactive power production by X on generator Y. The instructions will be broadcast to the different parties by telephone, computer actions, fax or other communication systems.

Where a TSO-control room is also in charge of switching in networks, it is possible that one or more instructions will have to be performed by the TSO-operators themselves. Then the sub-process 'Switching' is part of the total process. The objective of the 'Switching' sub-process is to perform the switching instructions, e.g. by the remote control of their SCADA system.

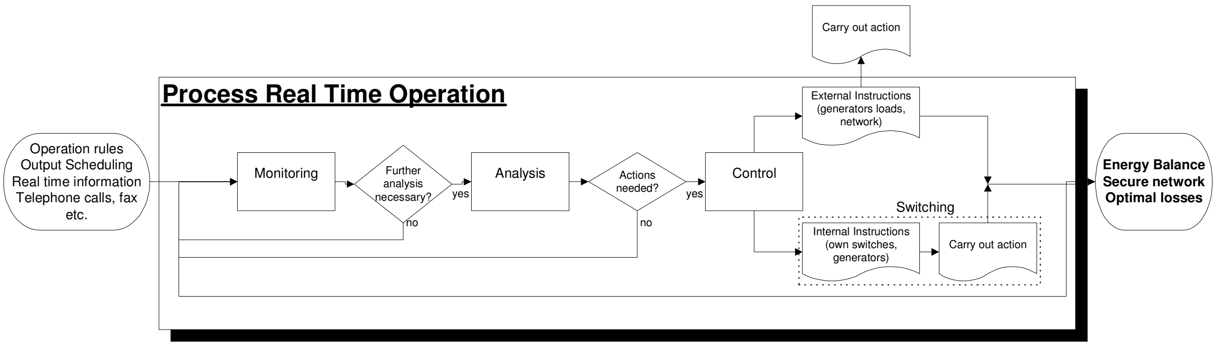
Where the control center has the TSO task to control some generator actions (e.g. pumped storage plants), switching could also include any generator actions carried out by the Control Room operators. A last part of the Real Time Operation-process could be a check as to whether the different parties have carried out the instructions and the instructions have led to the desired effect. For the purpose of this study we assume that this check is part of the 'Monitoring' sub-process.

We define three **outputs** of the Real Time Operation process:

- Guaranteed Energy Balance
- Secure Network
- Minimal energy losses

[3] Note: Not all TSOs perform the task of minimising losses.

FIGURE 3: PROCESS DESCRIPTION REAL TIME OPERATION



2.4 After the Fact

The After the Fact process covers the analysis and reporting of what has happened on the transmission system. Typically 'After the Fact' activities take place after the day of operation. The objective of the After the Fact process is to provide feedback information on what has happened on the transmission system to enable issues to be resolved.

The After the Fact process focuses on three areas: Energy Balance, Transmission Network Security and Ancillary Service. For these three areas sub-processes are distinguished: Monitor, Investigate, Analyze and Report. These sub-processes are detailed for the different areas in TABLE 2. Although there is consensus about the general functional description of the After the Fact Process, the frequency of the activities performed is different for each TSO. It is shown in TABLE 2 that most of the TSOs perform some kind of daily routine monitoring/reporting for network, energy and ancillary service issues. For all other issues the frequency of the activities varies for the different TSOs.

2.5 Support

Support covers the activities that enable the operational processes Operations Planning, Scheduling, Real Time Operation and After The Fact. It is identified that support for these processes mainly consists of IT-systems or IT-related support. Other support issues are considered to be minor (e.g. training, overhead) or are directly attributed to the individual processes.

Since IT is the major component of the Support process, the TSO Comparison Group decided to study the IT strategy of TSOs in more detail. It was concluded that the IT strategy of the member TSOs is very different. For example, some TSOs carry out almost all IT activities with their own personnel whilst others outsource nearly all IT activities, including development of TSO specific applications and IT system maintenance.

It is also shown that TSOs rely more and more on off-the-shelf solutions of vendors, rather than relying on their own software developments. TSOs only build their own software solutions in the case of very specific TSO

TABLE 2: ACTIVITIES OF THE AFTER THE FACT PROCESS

		Activity Level			
Task Description		Daily	Weekly	Monthly	<Monthly
Transmission Network Monitoring	Routine Network Monitoring	15 TSOs	1 TSO	1 TSO	1 TSO
	Network Performance Analysis	4 TSOs	9 TSOs	4 TSOs	3 TSOs
	Network Performance Report	1 TSO	1 TSO	7 TSOs	11 TSOs
	Incident Investigation:	1 TSO	4 TSOs	5 TSOs	10 TSOs
Energy Monitoring	Routine Generation & Interconnector Monitoring	18 TSOs		1 TSO	1 TSO
	Generation & Interconnector Performance Analysis	8 TSOs	1 TSO	2 TSOs	9 TSOs
	Detailed Output Reporting	14 TSOs	1 TSO	2 TSOs	3 TSOs
	Hydro Generation Assessment	14 TSOs	1 TSO	2 TSOs	3 TSOs
	Energy Performance Report			4 TSOs	16 TSOs
	Incident Investigation:	2 TSOs	1 TSO	5 TSOs	12 TSOs
Ancillary Services Monitoring	Routine Ancillary Service Monitoring	16 TSOs	2 TSOs	2 TSOs	
	Ancillary Service Performance Analysis	9 TSOs	1 TSO	9 TSOs	1 TSO
	Ancillary Services Performance Report			4 TSOs	16 TSOs
	Incident Investigation:	2 TSOs		3 TSOs	15 TSOs

related issues.

TSOs have very different reasons for investing in IT systems. Whilst some TSOs use IT systems whenever possible, the majority of the TSOs make a cost-benefit analysis. In this cost-benefit analysis the trade-off between using own staff or IT systems is implicitly incorporated. Another important factor in the choice for IT systems is the influence on power system reliability.

Not surprisingly, FIGURE 4 shows that the most important IT system of the TSOs is the SCADA/EMS system. It is found that on average more than half the IT costs of a TSO are spent on SCADA/EMS and related activities such as a Training Simulator. Other applications, such as network analysis tools, forecasting tools, information exchange and market based applications are less significant.

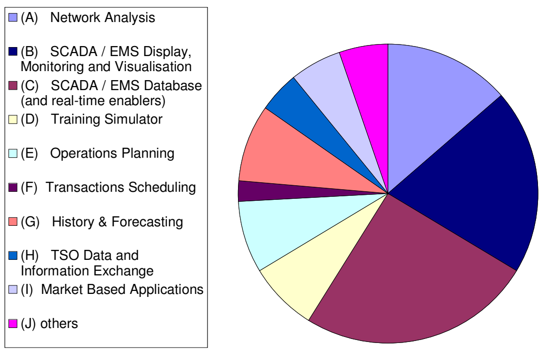


FIGURE 4: AVERAGE SHARE IN TOTAL IT COSTS OF DIFFERENT IT SYSTEMS

3 Collection of Performance Measures

The TSO Comparison Group's early years were spent identifying high-level common denominators (e.g. frequency, voltage) that underlie TSO operating practices, and the external driving factors (e.g. market environments, quality of service standards) that prompted the use of those particular practices. Building on this knowledge of different operating approaches, the TSO Comparison Group focused on developing meaningful Performance Measures (PM) for the TSO group. TABLE 3 shows examples of Performance Measures for the five TSO processes (see FIGURE 1) and overall TSO Performance.

TSO Comparison Group members fill out a performance measure questionnaire annually, using the comprehensive performance measures definition handbook, which provides definitions, background and examples of the performance measures and reference data.

TABLE 3: EXAMPLES OF TSO PERFORMANCE MEASURES AND REFERENCE DATA

Operations Planning (1 year to 2 weeks before day of operation)
– Number of Planned Transmission Outages
– Number of Planned Generating-unit Outages
Scheduling (2 weeks to 1 day before day of operation):
– Accuracy of peak load forecast
– Accuracy of minimum load forecast
– Transmission congestion: Generation constrained "on".
– Foreseen transmission concerns
– Scheduled transmission outage requests
– Scheduled generation outages
Real Time Operation (Day of Operation):
– Frequency control performance
– Average overall system deviation
– Generation and load instructions
– Personnel on shift
– RTO transmission outages taken
Support
– Operator training hours of teachers
– Training hours per operator
– Number of SCADA database points (Status points, Analog points, Control points)
Overall Performance:
– Transmitted energy at risk
– Response Time of Area Control Error or Frequency
– Energy unsupplied due to 'unsupplied energy incidents'
– Unsupplied energy incidents
– Voltage excursions
– Average time to return to normal situation after a fault
Reference Data
– Number of Staff in Full Time Equivalents, separately for each process
– Costs, separately for each process and network losses
– Network date, including e.g. Circuit Ends, Line lengths, Generators, Peak Load, Transmitted Energy, Interconnectors.

Since proper data quality is essential for benchmarking, the group puts a substantial amount of effort into checking data and understanding the definitions. Besides a mechanical check using 'validity checks', 'trending analysis' and 'ratio analysis', during the workshops a separate validation working group validates the most recent database.

At present, the TSO Comparison Group has an annually updated Performance Measure database with performance measure data from 2000 to 2007 available to its members.

4 Benchmark Models

Initially, performance measure data was normalized using various combinations of performance measures and reference data. Although this provided some information about TSO systems and operations, the information was too detailed and provided little indication about the strengths and shortcomings of each TSO's organization and operation for TSO Management. Therefore, the group decided to evaluate TSO performance in a more systematic way. For this purpose, the group decided to use a more advanced benchmark.

4.1 Benchmarking Model

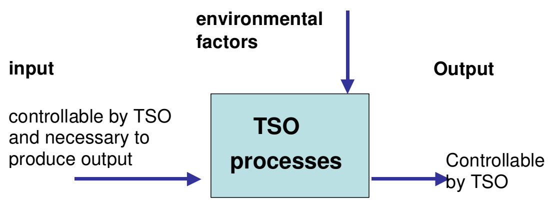


FIGURE 5: BENCHMARKING MODEL FOR COMPARISON OF TSO PROCESSES[4]

TSO processes are modeled as shown in FIGURE 5. We define the different elements as follows:

Inputs - the human resources (FTEs) and capital required to produce the output;

Environmental factors - describe the surroundings of the System Operation activities, this includes the network that is operated, the regulatory circumstances, the use of the network etc. Environmental factors cannot be influenced by System Operation, but do influence the relation between output and input;

Output - the product that the TSO produces. For System Operation this is defined as a balanced and secure system. This Output is controllable by the TSO.

4.2 Selection of Inputs, Outputs and Environmental Factors

Based on the process descriptions and key activity lists which are shown in section 2, input, output and environmental factors for the benchmark models of each of the individual processes have been defined.

In general, **Input Factors** of a benchmark model are the resources that are put into the process to influence the Output. Input factors that can be considered for the processes are:

- *Staff:* Number of staff (expressed in Full-Time Equivalents, FTEs) working in the particular process;
- *Costs*: Costs of the operating tools i.e. control centers, SCADA/EMS systems.

The members of the TSO Comparison Group decided that in the first instance the performance of the processes "Operations Planning", "Scheduling", "Real Time Operation" and "After the Fact" would only be measured based on the "staff" input. In other words, performance will be measured by "productivity" (Comparable Output per FTE). The costs of the operating tools are considered under the "Support" process and will be benchmarked separately.

Input Factors: Number of staff (FTEs)

The **Output Factors** of a Benchmark model are defined as products that are the result of input factors, the performance of the benchmarked process, and environmental factors that influence this process. In "normal" (input-output) production environments, it is fairly easy to define Output Factors, e.g. items (goods, services) being produced. However, when benchmarking System Operation processes, output factors are less obvious.

The TSO Comparison Group has defined measures for potential output factors:

1. Unsupplied Energy;
2. Energy Supplied at risk, i.e. Energy not supplied under (n-1);
3. Voltage control: e.g. the number or duration of Voltage excursions;
4. Minimisation of losses;
5. Frequency deviation (for island networks);
6. Area Control Error (for interconnected networks).

Since market facilitation is gaining importance for more and more TSOs, providing an accurate load forecast is for an increasing number of markets an important output of the TSO. Another relevant output of the System Operation Process is therefore:

7. Accuracy of Demand Forecast.

Output factors are supposed to be influenced by the TSO itself; otherwise this could be considered under environmental factors. A possible test could be the following: Can the TSO improve the output-factor with extra input (in this case FTE) or will the output-factor decrease with less input? If one of these statements is true, it is a real output-factor.

The influence of the input factors (FTEs) of the System Operation processes on the output factors listed above is questionable. As staff can definitely influence these

[4] This picture is a simplified presentation of the complete model which is presented in [1].

TABLE 4: ENVIRONMENTAL FACTORS FOR OPERATIONS PLANNING AND SCHEDULING AND THEIR ASSESSED RELEVANCE ('+++' IS VERY RELEVANT, '++' IS RELEVANT AND '+' INDICATES LIMITED RELEVANCE.

	Operations Planning	Scheduling
Circuit Ends (i.e. lines, transformers)	+	++
Generating units	+++	++
Interconnections with other TSOs	++	+
Planned/Scheduled Transmission Outages	+++	+++
Planned/Scheduled Generating-unit Outages	+++	+++
Foreseen Transmission Concerns	++	+++
Meshed or 'weak' system	+++	
Reliability (system security) standards adopted	+++	
Operating Standards		+++
Operating Procedures		+++
Nature of load and customers	+++	++
Nature of energy production (hydro, fossil fuel, nuclear, wind, geothermal)	+++	++
Weather factors	+	++
Regulated or deregulated market , also regulations/rules	++	+++
Geographical area [km^2]		++
Asset owner or not		

output factors, one could argue that the number of staff (FTEs) could influence the quality of the output. However, it is a common belief that the Unsupplied Energy, Energy Supplied at risk, Voltage excursions, Frequency deviations, Minimisation of losses etc. could not be decreased by adding more RTO staff to the control center. In other words, it is questionable if the 'Output' of the processes is necessarily better for a TSO with zero incidents than for a company with more incidents. This makes these variables less useful as output factors for the Benchmarking Model.

After several workshop discussions, the TSO Comparison Group defined the output of the System Operation processes as 'balancing the system and ensuring system security'. Since all TSOs are deemed to have a 'balanced and secure system', this output is considered uniform for all the TSOs of the TSO Comparison Group.

For this reason we consider using such a uniform output for this benchmark model. It is thus assumed that all TSOs, adjusted for their size, deliver similar outputs.

Using a uniform output enables a more transparent comparison between the member TSOs of the use of resources. However, the differences in quality should not be ignored. Therefore, the quality measures that are mentioned above are plotted against the benchmark results in a key graph. This key graph is discussed in section 5).

Output Factor: uniform

Since the TSO Comparison Group would like to show the differences in performance of TSOs, the factors mentioned above are used for plotting the Key Graph, which is described in section 5.

Environmental Factors describe the surroundings of the TSO activities that influence the complexity of the task to be performed in the different TSO processes. These factors are measured by complexity indicators and will be used for adjusting the benchmark model to the environments of the TSO.

As an example, for the processes "Operations Planning" and "Scheduling" several possible Environmental Factors are shown in TABLE 4, including the assessed relevance of the factors by the member TSOs. In the understanding of the member TSOs, the physical network size of the network of the TSO (number of lines, transformers, generators connected, interconnectors) is an important environmental factor for the 'Operations Planning' and 'After the Fact' processes. Because planning of Transmission and Generation outages is a main activity in both the Operations Planning and the Scheduling process, the number of Planned Transmission and Generation Outages is considered to be an important environmental factor for these processes. For the After the Fact process, the number of incidents is added (e.g. interruption of supply and voltage incidents).

Considering the restricted number of TSOs, we have to limit the number of environmental factors in order to obtain a statistically relevant benchmark model. A possible way to proceed is to combine different environmental factors into one composite environmental factor. From the selection of environmental factors, one group of environmental factors describes the physical size of the transmission system. This group consists of Circuit Ends, Generation Units and Number of Interconnectors. These parameters are combined in a composite environmental factor Environmental Factors EF_1:

$$EF_1 = CE + w_1 GU + w_2 IL \qquad (1)$$

where:

CE = number of circuit ends

GU = number of generating units

IL = number of interconnectors

TABLE 5: SELECTED PARAMETERS FOR BENCHMARK MODELS

	Operations Planning	Scheduling	Real Time Operation	After the Fact
Network Size: Circuit Ends + 5 * Generating Units + 5 * Interconnectors	EF_1		EF_1	EF_1
Planned Transmission Outages, Generation Outages and Transmission Concerns	EF_2			
Scheduled Transmission and Generation Outages		EF_1		
Scheduled Transmission Outages			EF_2	
Unsupplied Energy Incidents				EF_2

w_i = weight assigned to Environmental Factors i.

Using the expert view of the members of the group, the following assumptions on weights were made:

$w_1 = 5$;

$w_2 = 5$.

This can be interpreted in such a way that Generating Units or Interconnectors need five times as much effort as a circuit end. The effect of the assumptions on the results is assessed by means of a sensitivity analysis. However, we found the results are not dramatically influenced because of a minor change in these assumptions.

Since costs in Transmission System Operation are not only driven by the size of the network (like in environmental factor EF_1), in a similar way several other factors are examined which could reflect the activities performed by the TSO. For example, apart from some system related activities like preparing demand forecasts and defining load flow models, a main activity for Operations Planning is planning the generation and transmission outages in the network. Including the number of planned outages, this information is added to the model.

TABLE 5 provides an overview of the parameters selected for the benchmark models Operations Planning, Scheduling, Real Time Operation and After the Fact. Based on the experience of the members of the TSO Comparison Group and on proven statistical relevance, composite environmental factors are defined.

4.3 Support process

In section 2.5 it is concluded that the Support process is largely influenced by IT systems. This means that IT systems largely influence the cost of the Support process. As shown in FIGURE 4, the largest part of the IT cost is SCADA/EMS related. The TSO Comparison Group therefore considers the following factors as the most important cost-drivers of the Support process:

1. Size of the SCADA/EMS system, measured in database points (status, analog, control);
2. Increase in size of the SCADA/EMS system, measured in database points (status, analog, control).

At the time of writing this paper, the relevant data on SCADA data points is being collected. Based on these values, the Support benchmark model will be run.

4.4 Qualitative Benchmark Results

In this benchmark model we are comparing the efficiency of each TSO with the comparable efficiency of the other members of the TSO Comparison group, using a linear Ordinary Least Squares (OLS) model. Although a logarithmic OLS model was also tested, in general it can be concluded that the linear relationship fits best. This is in line with the general expectations of the members of the TSO Comparison Group, which do not see large economies of scale in most System Operation processes for TSOs.

This results in the following formula (2) and the parameters of TABLE 6.

$$Z_i = c + \beta_1 EF_{1,i} + \beta_2 EF_{2,i} \qquad (2)$$

where

Z_i = estimated number of FTEs for TSO i;

c, β_1, β_2 = factors, calculated by the COLS model;

$EF_{j,i}$ = environmental factor j for TSO i.

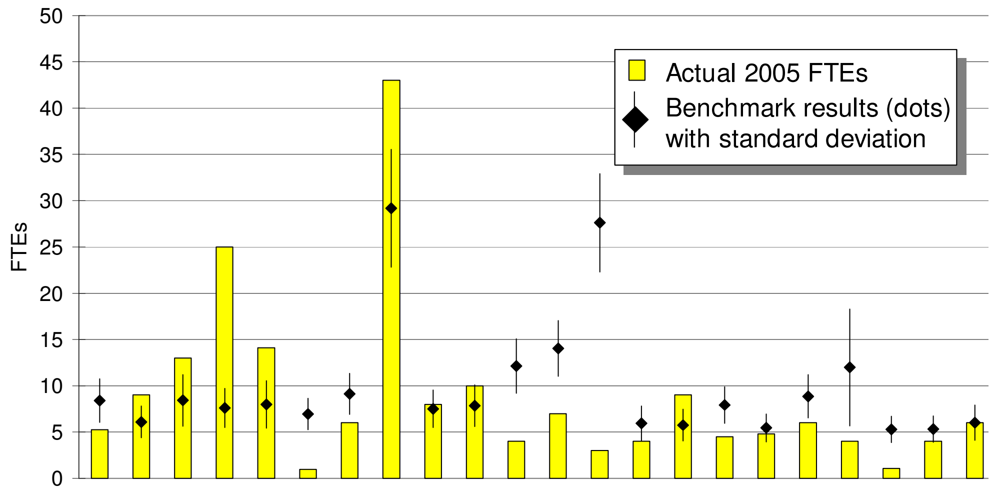


FIGURE 6: RESULTS OF THE BENCHMARK MODEL FOR THE AFTER THE FACT PROCESS, WITH ANONYMOUS RESULTS. THE BARS REPRESENT ACTUAL FTES (FROM PERFORMANCE MEASURE DATABASE) OF THE TSOS, WHERE THE DOT REPRESENTS THE NUMBER OF FTES AS CALCULATED BY THE BENCHMARK MODEL.

TABLE 6: RESULTS OF THE REGRESSION ANALYSIS FOR THE LINEAR COMPLEXITY FUNCTION: FACTORS TO BE USED IN THE BENCHMARK FORMULA[5,6]

	c	β_1	β_2
Operations Planning	3	0.002	0.0006
Scheduling	5	0.0009	
Real Time Operation	20	0.006	0.0006
After the Fact	5	0.0004	0.07

Using the values of the Estimated Number of TABLE 6, FTEs can also be calculated for each TSO. This number coincides with the number of FTEs needed for the process, when the TSO would operate at the average efficiency of the total group. This is shown in FIGURE 6 together with the actual number of FTEs. An anonymous graph is presented here for confidentiality reasons. Labeled graphs are however available to members.

Using the results of FIGURE 6 each TSO can conclude whether its number of FTEs for the After the Fact is higher than average (central tendency), lower than average or about average, taking standard errors into account. For members, similar graphs are available for all other processes.

The model is used for finding out-performers on each of the TSO processes. Since all TSOs are different, 'activity lists' (see section 2) are used in this process as well i.e. if a TSO outperforms in a specific process because their activity in this process is very limited, this will be shown in the 'activity lists'. During workshops outperformers are invited to explain their position in the Benchmark results. The objective of these sessions is to learn from one another.

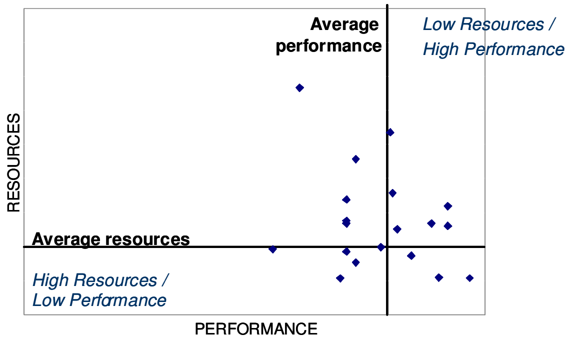
5 Key Graph

In addition to the detailed benchmark results, the TSO Comparison Group developed a Key Graph which provides an explanation of the results of the Benchmark on just one single slide. This includes a two-dimensional presentation in which the use of resources of a TSO (i.e. the Benchmark Results) is compared to the performance of the TSO. An example is provided in FIGURE 7.

[5] As discussed in [1], the statistical relevance of the parameters is tested, using both adjusted R^2 and t-statistic. T-statistic of β_1 and β_2 should be at least 2, which means that there is less than 5% probability of inference error in significance terms. We are therefore allowed to accept the significance of our estimated coefficients.

[6] The number of digits presented in these results is reduced for confidentiality reasons. The full number of digits are available to members of the TSO Comparison Group.

FIGURE 7: EXAMPLE OF KEY GRAPH OF THE BENCHMARK RESULTS, EACH DOT REPRESENTS A TSO



5.1 Resources Axis

The Resources Axis in FIGURE 7 represents the result of the Benchmark studies discussed in section 4. The value plotted in the diagram of the TSO is the quotient of the input (FTEs or Cost) calculated with the model and real input of this TSO i.e. a TSO scores high on this axis when the resources used are lower than the resources calculated by the model.

5.2 Performance Axis

The TSO Comparison Group defined measures that indicate the performance of System Operation. These measures are:

1. *Average Interruption Time (AIT)*, defined as Energy not Supplied divided by Transported Energy;
2. *Voltage control*, e.g. the number or duration of Voltage excursions;
3. *Average Overall System Deviation*, defined as frequency deviation for island networks and Area Control Error for interconnected networks;
4. *Response time* to Area Control Error (ACE) or Frequency Error;
5. *Accuracy of peak load forecast*;
6. *Accuracy of minimum load forecast*.

It should be noted that the System Operation department can only partly influence these performance factors. For example System Operation can influence the number of Voltage excursions, but it should be noted that this job is easier in a smaller and/or more meshed system.

Furthermore, the different performance measures are not equally important. This means that the different performance measures need to be weighted. In the current project, the weights are being discussed within the TSO Comparison Group.

6 Conclusions

In this paper we present an approach for benchmarking Transmission System Operation processes. The results of the benchmark studies for the different processes are presented in figures that show the actual number of FTEs for the different processes and the number of FTEs calculated with the Benchmark Model. A conclusion from these figures could be drawn for each TSO and each process i.e. a TSO can see its position with regard to the ‘average’ TSO for each process. Moreover, the TSO can identify which other TSOs are useful peers to learn from. As environments vary for the different TSOs, for example due to the regulatory environment, the activities within the various processes could be different. Possible explanations of the differences could be found in the Key Activity Matrices of the various processes. In these matrices, the TSOs indicated which activities they performed and the intensity of each activity.

By completing the benchmark models for the processes Real Time Operation, Scheduling, Operations Planning and After the Fact, a useful set of quantitative benchmark models has been developed which show the TSOs their position in the efficiency ranking of the total group of TSOs. Moreover, qualitative information is collected and structured to allow possible explanation of the results. Currently, the TSO Comparison Group is implementing the benchmark model for the process ‘Support’, which enables the creation of an overall benchmark model for all five processes of System Operation together and the presentation of the benchmark results in easy to understand key graphs.

The model will be further improved by adding more details on the circumstances in which TSOs operate. Therefore, besides the effort put in to preparing the key activity lists, a separate working group is studying the influence of the market situation in the different countries.

7 ACKNOWLEDGMENTS

The presented work was carried out by the TSO Comparison Group. The following is a list of members of the TSO Comparison Group:

Nemorio Gonzalez	CFE, Mexico
Chai Ming Mak	CLP Power, Hong Kong
Anthony Ng	CLP Power, Hong Kong
Peter Hoffmann	E.ON Netz, Germany
Marcus Rohleder	E.ON Netz, Germany
Laura Walsh	Eirgrid, Ireland
Jean-Louis Leonard	Elia System Operator, Belgium
Bernard Magoro	ESKOM Transmission, Republic of South Africa

Rudolf Baumann	Swissgrid, Switzerland
Timo Kaukonen	Fingrid, Finnland
Gudmundur Asmundsson	Landsnet, Iceland
Ragnar Stefanson	Landsnet, Iceland
Alex Carter	National Grid, United Kingdom
Braz Campanholo Filho	Operador nacional do Sistema Elétrico - ONS, Brasil
Albert DiCaprio	PJM Interconnection, USA
Pawel Antos	PSE-Operator, Poland
Jaime Sanchiz Garotte	Red Electrica de Espana, Spain
Rui Pestana	Rede Eléctrica Nacional, Portugal
Michael Rogge	RWE Transportnetz Strom, Germany
Laith Ahmed Albassam	Saudi Electricity Company, Kingdom of Saudi Arabia
Lars Voldhaug	Statnett, Norway
Ole Gjerde	Statnett, Norway
Thomas Thor	Svenska Kraftnät, Sweden
Jan van Putten	TenneT, Netherlands
Mikhail Kapellas	TransEnergie a Division of Hydro Quebec, Canada
Patrick Toner	TransEnergie a Division of Hydro Quebec, Canada
John Campbell	Transpower NZ, New Zealand

8 Literature

[1] Dicaprio, Albert et al., “Real Time Operation” Multi-Dimensional Benchmarking of 20 TSOs, Bulk Power System Dynamics and Control conference – VI. August 22—27, 2004, Cortina d’Ampezzo, Italy.

[2] Dicaprio, Albert et al., Benchmarking System Operation Processes for 20 international Transmission System Operators, Cepsi Conference – November 2006, Mumbai, India.