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Electrical Power Delivery improvement in Portugal through Quality Function Deployment

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***Abstract*—Quality Function Deployment was applied to the electrical power delivery sector in Portugal. This led to identifying critical dimensions which customers would like/want to see improved in the electrical product and service. In order to achieve these improvements a set of solutions was found and provided to the Portuguese utility Company. In this paper we describe all of the steps of the work done and present the customer Satisfaction Index scores measured before the study was conducted in 2001 and at the end of 2006.**

***Keywords*—Power Quality, Quality of Service, Total Quality Management, Quality Function Deployment, Customer Satisfaction Index, Continuous Improvement in Power Quality and Utilisation.**

I. INTRODUCTION

All companies involved in electrical power delivery are continuously evaluating decisions related to the investments that they have to make in their infra-structures and processes. Small investments can lead to lower levels of service quality, while large investments can induce high quality, which is not always widely recognized and valued by all customers, with a significant impact on global operating costs. For top managers it is thus fundamental to identify accurately, for each customer segment and region, which dimensions of service customers are dissatisfied with, or considered to provide more added value. Additionally, it is important to have a quantifiable notion about which dimensions of quality are worthwhile concentrating resources on, so as to maximize the benefit/cost for each improvement project. The scope of this work lies in this area and consists essentially in transposing Total Quality Management concepts to the electrical power delivery sector, and more precisely in the application of Quality Function Deployment (QFD) to this sector in Portugal.

Our fieldwork led to the identification and quantification of a collection of critical dimensions, which customers value and would like to see improved in product and service related to electrical power delivery. Furthermore, a set of solutions were found, as well as their capability to improve the previously identified dimensions. The rights and obligations of all the stakeholders involved are also highlighted. The solutions found were provided to the Portuguese utility Company, which implemented them and later validated their impact with an in depth study.

In this paper we will describe all the steps of the work conducted and present the customer Satisfaction Index (CSI) scores measured in 2001, before the study was conducted, and the expected improvements. We also highlight, for this period of time, the evolution in the quality of service parameters in the Portuguese electrical delivery system, according to our survey and the official European reports for these parameters.

II. WHAT IS QFD

QFD stands for *Quality Function Deployment*, which means the unfolding or front to rear development of quality function. It is an advanced quality management tool that integrates concepts from *Concurrent Engineering* to the improvement (or development) of (new) products and services. The first stage of a QFD application consists in focusing on a selected sample of customers from a specific sector to auscultate, as accurately as possible, what are the most important requirements that they would like to see integrated in the product/service and must be provided by the supplier. This phase involves processing verbal information through

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Concepts Engineering. The second stage involves mobilizing resources to realize the explicit and implicit wishes revealed by the customers in the first stage. This tool concentrates the attention of the organization at the end of the supply chain of the product/service – the customers – and carries out a front to rear development of the quality function in a process where all the identified solutions are weighed towards improving the overall process which allows the organization to improve what they offer so as to meet customers' expectations. Identifying the ***whats*** (what the customer really wants) and the ***hows***, how we can meet their needs, by what means, with what technologies, underpins this methodology. Economic principles are always present. Each solution must be analysed, quantified and evaluated with a view to maximize benefit/cost relationships [1].

III. Fieldwork

The goal of our QFD application to the electrical power delivery sector in Portugal was to identify, in an innovative way, the concepts related to electrical power delivery and solutions with high level of applicability to improve customer Satisfaction Index and, if possible, exceed customer expectations. This work was carried out according to the six steps that follow.

1. Listening to customer voices

One crucial aspect for successful QFD application is the customer sample used. Chosen customers have to be informed and highly involved with the subjects under study. We applied the premise that if we identify the requirements of more demanding and skilled customers, then the improvements of the processes to satisfy their needs will please all the customers. This strategy aims to cover all the customers' requirements [2] through successive in-depth interviews (see Fig.1). To do this, we made a previous prospective study entitled *The Power Quality Panorama in Portugal* [3] to find indirectly who can potentially integrate our sample. The criteria chosen were as follows: 1. customer representativity (industrial, commercial and residential segments); 2. Electric energy intensive segments; 3. customers highly dependent on power quality for their productivity; 4. customers who complain; 5. Overall geographic territory cover and 6. Utilization leaders, equipment producers and suppliers and power quality experts. In Table 1 we can see a sample of the 196 customer voices gathered.

Figure 1 – Information gathered from each interview [4].

Table 1 – Sample of customer voices.

• Our needs are increasing continuously due to high levels of automation in our processes. We have more and more information technologies controlling and supervising our manufacturing!
• With the installed power that we have now, for the new factory we are considering the connection to 150 kV.
• The utility never listens to customers, which is the most basic procedure in any quality management procedure.

2. Transformation of customer voices into requirements

Requirements have the same information as customer voices, but are expressed in terms of a more concise language. For this operation, one inter-functional or project team (team), comprised of customers, experts and staff from the utility, was formed.

From the 196 voices gathered in step 1, 236 requirements and 35 images related with the product and service under study were identified. After this, *MPM* ("Method for Priority Marking") was applied (see Table 2) [5], thus reducing the number of requirements to 32. With the application of the *KJ Method* (another advanced quality management tool), we identified the dimensions more valued by Portuguese customers related to Electrical Power Delivery, which are:

1st - Supply Reliability;
2nd - Overall cost and
3rd - Attention to customer needs.

Table 2 – Sample of the requirements identified.

• Schedule and, whenever possible, notify by efficient means about programmed interruptions.	O	8,29
• It is fundamental decrease the number of interruptions and micro-interruptions for continuous process industries.	P	8,47
• Rights and responsibilities of utility and customers must be clearly explained in the energy supply contract.	O	6,88
• Provide the means available for customers to complain and state their needs efficiently.	O	7,24
• The interface between the utility and customers must have appropriate technical skills to understand, solve or address problems quickly and efficiently.	P	7,76
• Staff who receives customers' complaints knows exactly what is happening in the field and provides up-to-date information about the real situation.	A	7,76
• It is fundamental go into the field, visit the facilities and talk to customers.	A	5,59

3. Classification and quantification of the requirements

After identifying the requirements, the next step was to classify and quantify their importance, according to the customers' opinions. This was carried out with the application of a *Kano Questionnaire* [6]. In effect, the identified requirements were presented to customers who had given us their opinion, leading to the following classification: (O) Obligatory, (P) Proportional, (A) Attractive, and (I) Indifferent; they also quantified their importance on a scale from 0 to 9. Table 2, column 2, presents a sample of these data. We thus obtained, by customer segment, accurate information about the requirements that are more likely to promote high levels of customer satisfaction.

We finished this step with a synthesis analysis of all 32 requisites, grouped around the *Quality Dimensions* more valued by customers (Table 3).

TABELA 3 – QUALITY DIMENSIONS MORE VALUED BY ALL CUSTOMERS.

1st	Continuous improvement of quality product and service.
2nd	Utility assumes more responsibility.
3rd	Consider the quality as a crucial strategic vector.
4th	Organization culture = Obsession by the customer
5th	Technical auditing available to customers.
6th	It is fundamental to decrease overall cost.
7th	It is important differentiate the service to different segments.

Emergence of new corporate concept

After classifying and quantifying requirements, the next step was to identify a *new corporate concept* translated into a slogan which reflects the needs of customers, and contributes to the implementation of the requirements. This was achieved through the use of *Pugh Methodology* [7]. After some iteration, the dominant concept found by the team was:

"Effective usefulness without worries – supplying value!"

This concept points to the need to introduce improvements in the service supplied. The modern customer does not buy a product or service; they pay to use a product or service without worries. It is thus vital that the product/service received has the capacity to satisfy customer needs and if possible to exceed their expectations as a strategy to retain them or increase their loyalty.

With this step we concluded the first stage of *Concepts Engineering*. We processed verbal information and identified the ***whats***. We now have a set of structured requirements, related to what customers want to receive in the product and service that the utility should supply to them; and a corporate concept to achieve their implementation.

4. Definition of product and service characteristics

In this fist step of the second stage we have to identify the ***hows***, find the solutions which allow the processes to meet customer needs. These solutions are designated by *Characteristics* in the QFD terminology, and integrate the means, resources, tools and needed technologies to meet the customer requirements. The Characteristics must be identified/defined in high detail and be described in technical and quantified language [5].

The team's know-how in matters related to electrical power production, transport and distribution is a crucial issue to accomplish this operation successfully – finding the best solutions! To carry them out the team was complemented with people coming from the equipment supplier sector, equipment installers, utility staff and external experts in Power Quality. Our goal was to identify the best solutions to address the customer requirements. Throughout this task we often also employed *"Benchmarking"* and *"Brainstorming"* tools.

By general consensus the 73 *Characteristics* identified were grouped under the flowing domains:

1. Quality of the Wave – 16 characteristics;
2. Power Reliability – 26 characteristics;
3. Commercial Quality – 31 characteristics.

Whereas domains 1. and 2. are predominantly related to product delivery, domain 3. is related to service.

We emphasize the different numbers of characteristics in each domain, which reveals the areas where one more intense intervention is necessary. In Table 4 (column 1) we present all the characteristics.

TABLE 4 – CHARACTERISTICS IDENTIFIED, GROUPED BY DOMAINS AND DECREASING ORDER BY BENEFIT/COST.

1. Quality of the Wave	Technical Relevance	Impl. Dif.	Benef./ Cost
Adopt Quality of Service Regulation with explicit rights and duties for the utility and customers.	571.94	1	571.9
Interconnection rules based on quality criteria policies.	212.94	1	212.9
Identify and classify polluting customers.	350.94	4	87.7
Update the L.V. regulation based on new realities in the sector.	86.28	1	86.3
Monitor and record the relevant parameters related to Power Quality delivered.	317.24	4	79.3
Reinforce the capability of overloaded transmission lines.	297.23	4	74.3
Voltage Surge Suppressors (Zn O) at individual customer level.	129.13	2	64.6
Voltage Surge Suppressors (Zn O) at M.V. level.	246.77	5	49.4
Promote lower THD impact technologies.	94.94	2	47.5
Reinforce the capability of Power Transforming Station Units.	174.94	4	43.7
Decrease the length of L.V. lines.	204.77	5	41.0
Install lightning protection systems.	139.94	4	35.0
Adapt infra-structures to ongoing distributed generation.	174.94	5	35.0
Automatic voltage regulation systems.	174.77	9	19.4
Dual capability systems for harmonic mitigation and power factor correction.	69.28	5	13.9
Transformers with auto-cancelling capability for some harmonics.	69.94	7	10.0

2. Power Reliability	Technical Relevance	Impl. Dif.	Benef./ Cost
Inform customers efficiently about their duties and responsibilities.	136.94	1	136.9
Install nesting stork supports near the H.V. posts.	377.77	3	125.9
Efficiently disclose the real situation related to energy delivery.	244.94	2	122.5
When efficient solutions are identified transpose them to solve similar situations.	115.88	1	115.9
Good maintenance of neighborhood infra-structures.	303.77	3	101.3
Establish channels to carry field information to the coordination service efficiently.	283.69	3	94.6
Schedule the service interruptions correctly and inform them efficiently.	163.94	2	82.0
Reduce repair time and service replacement to a minimum.	311.77	4	77.9
Increase the Average Time Between Failures.	305.94	4	76.5
Emergency action plan adapted to the process sensitivity of each customer segment.	290.94	4	72.7
Gradually abandon traditional techs and adopt "Ride Through Capability Technologies"	127.71	2	63.9
Repair works on tension - without service interruption.	308.94	5	61.8
Premium maintenance and insulator cleaning.	358.94	6	59.8
Gather quality of service parameters and supervise	114.64	2	57.3

their progress closely.			
Increase in-depth studies on critical points.	109.24	2	54.6
Apply predictive maintenance to old equipment.	101.23	2	50.6
Create a data base with relevant parameters for each piece of equipment.	97.23	2	48.6
Thermographic inspections of equipment and lines.	132.59	3	44.2
Distributed generation near critical processes.	331.71	8	41.5
Increase redundancy in feeding.	284.94	7	40.7
UPSs to critical loads where micro-interruptions are frequent and costly.	241.94	7	34.6
Install fast automatic open and re-close protection systems.	176.77	7	25.3
Replace outdated equipment.	145.94	6	24.3
Install M.V. twisted semi-isolated cables.	175.94	8	22.0
Gradually put T&D lines underground	193.77	10	19.4
Increase access barriers to all T&D equipment.	49.94	3	16.6

3. Commercial Quality	Technical Relevance	Impl. Dif.	Benef./ Cost
Manual of good practices between the utility and customer.	399.94	1	399.9
Modernize the utility web-site to broadcast useful information to customer.	244.28	1	244.3
Guarantee reliability product and service in writing.	210.41	1	210.4
Based on data gathered the utility assumes the responsibilities without subterfuges.	188.41	1	188.4
Adopt the internal customer concept with awareness to the new scenarios in electrical sector.	275.23	2	137.6
Spread messages with automatic short message service (SMS) for groups or special customers.	273.23	2	136.6
Spread effectively the scheduled interruptions.	243.23	2	121.6
Increase toll-free phone efficient access points (800…)	215.64	2	107.8
Listen to and visit customers regularly.	420.69	4	105.2
Promote direct and efficient relationship with customer.	204.64	2	102.3
Give open access of customers to their data.	96.36	1	96.4
Develop appealing Web-site personalised for regions and customer segments.	96.41	1	96.4
Adopt the concept of internal customer and stimulate internal wealth competition.	88.71	1	88.7
Effectively disclose the contribution of each collaborator to continuous improvement and global quality service index.	86.84	1	86.8
Each collaborator assumes the responsibility as a consequence of their performance with customers.	240.69	3	80.2
Establish internal liberalisation goals by creating independent sub-sectors, managed by objectives.	293.64	4	73.4
E-mail available continuously and quickly answered.	145.41	2	72.7
Front office made up of people with skills and technical knowledge in electrical power delivery.	217.88	3	72.6
Technical consulting available to all customers.	429.23	6	71.5
Set a customer manager to each customer.	278.53	4	69.6
Efficiently inform about the tariff system using all available resources.	68.16	1	68.2
Whoever attends the customer knows, or has quick access to the information that they want to know.	222.23	4	55.6
Share the market and define rules of intervention for each segment according to their sensitivity or Power Quality Costs.	192.88	4	48.2
Put on-line simulations tools available for which the customer can reduce their energy bill.	92.71	2	46.4
Apply discounts as a function of the bill amount.	76.13	2	38.1
Adopt mechanisms to gather the performance of each utility collaborator.	144.23	4	36.1
Establish strategic alliances to sell other services in partnership.	71.88	2	35.9
Process the staff information gathered on time and spread the individual and collective performance indexes regularly.	104.88	3	35.0
Decrease the price of power contracted.	69.77	2	34.9
Support all the infra-structure expense up to the energy meter.	81.13	4	20.3
Establish a reward system to reward high performance staff levels.	53.06	3	17.7

5. *House of Quality*

The House of Quality (HQ) is the arrival point of our QFD application. This is a tool supported by a computational application where the information gathered in the previous steps is introduced (see Figure 2). In the lines of Room 1 the 32 requisites identified in step 2 were introduced, with the importance quantification (columns 3 of Table 2) in the chimney. In the columns of Room 2 the 73 *Characteristics* specified in Table 4 – column 1 are introduced. In each cell of Room 3 (called the correlation room) we do show how each specific characteristic contributes towards improving a specific requirement. The correlation intensity is attributed by the team and expressed on the following scale: Very Strong (9 points), Strong (3 points), Weak (1 point) and No Correlation (0 points). For each characteristic, the sum of the values that result from the multiplication of the correlation intensity by the importance of the requirements, reveals the *Technical Relevance* or potential contribution of that characteristic to improve the overall quality specified in the requirements. In the HQ this information is displayed in Room 5 and is presented in Table 4.

Once the *Technical Relevance* for each characteristic is known, another question arises. Is this information enough to trigger the implementation of solutions in the most efficient way? After a simple analysis, we conclude that this value is not sufficient. The team decided then to evaluate and classify the *Implementation Difficulty* for each characteristic, in technical and financial aspects, on a scale from 1 (low difficulty) to 10 (high difficulty). With these two parameters we generated the *Benefit/Cost* index (that results from the quotient of *Technical Relevance* by *Implementation Difficulty*), which allows a Pareto Graph to be built. Column 4 in Table 4, decreasing order by this parameter, shows which *Characteristics* to implement according to priority.

6. *HQ Final Results*

The conclusions from our HQ are drawn from reading the rooms, especially 4, 5, 6 and 7. Due to the size of the HQ (32x73 cells), it is not possible to explain their content in this paper in detail. As we have mentioned before, the most relevant data are presented in Table 4. We emphasize the dynamic nature of the process under study. With the HQ tool it is possible to keep results updated continuously in the most dynamic parameters, that are the requirements and their quantifications, as well as the progress made in the characteristics (Rooms 2 and 3). Once a first version is obtained, it is relatively easy for the utility to keep them up-to-date.

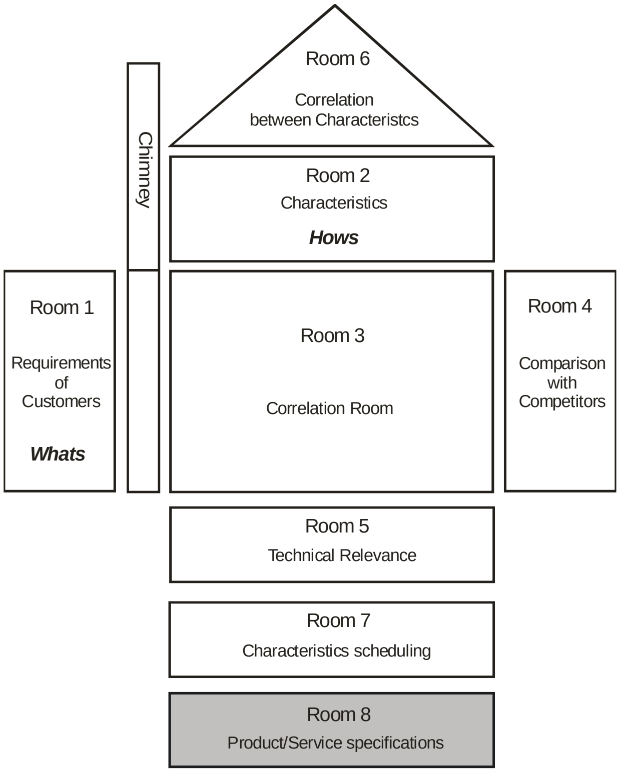

Figure 2 – House of Quality.

IV. TRANSPOSITION OF CONCLUSIONS TO THE PROCESSES

Due to the nature of the process in studying the transpositions of conclusions (*Characteristics* = solutions!) to the field, it was impossible to do so without the full involvement of the Portuguese utility. As we have mentioned before, all the work was done with the participation of the utility staff in the team project and the results shared with the EDP top managers. Our action priorities were as follows:

1. To educate and raise awareness, as widely and deeply as possible, for all of the stakeholders involved in modern Power Quality subjects, with a special focus on involving higher level teaching institutions to promote an update of their curriculum with the integration of the facts and new realities in these areas.
2. Producing articles and teach seminars to disseminate these subjects in the industrial and scientific Portuguese community ([9] to [12]).
3. Producing the first Manual of Power Quality for the Portuguese utility (EDP, S.A.) to disseminate, in first instance, to all of their Customer Managers and highly critical customers in the industrial and commercial sectors [13].
4. Selecting pilot facilities, characterized by high energy intensity, high Power Quality Costs and high sensitivity related to Power Quality and Reliability, to apply new methodologies and "Ride Through Capability Technologies", evaluate their impact and work as Case Studies for dissemination in similar situations.

V. VALIDATION OF RESULTS

Validation of the results in the electrical power delivery sector involves special constraints, due the extraordinary nature and size of the process under study. As far as these difficulties are concerned we can refer: – the amount of action areas involved, – the magnitude of some of the characteristics and the time required to put them into place, – the financial effort required, – uncertainty in the progress of the utility Governance, – the perspective of the market changing and the effects in investor behavior, to name only a few.

A. Measuring CSI in 2001

At the end of this work and before the implementation of the *Characteristics*, we decided to carry out an in-depth study to evaluate CSI related to each requirement (Table 2) and the overall CSI for the service perceived by all customers in 2001. This study was supported by a questionnaire given to a diversified sample, covering all the segments and territory. The answers to each question (satisfaction level with each requisite) were gathered on the following scale:

Answering Possibilities	Points
Extremely Dissatisfied	1
Dissatisfied	2
Satisfied	3
Very Satisfied	4
Delighted	5

In Figure 3 we present CSI values obtained for each of the 32 *Characteristics* gathered in 2001 (height of white column). We can see that these range between 2 (Dissatisfied) and 3 (Satisfied).

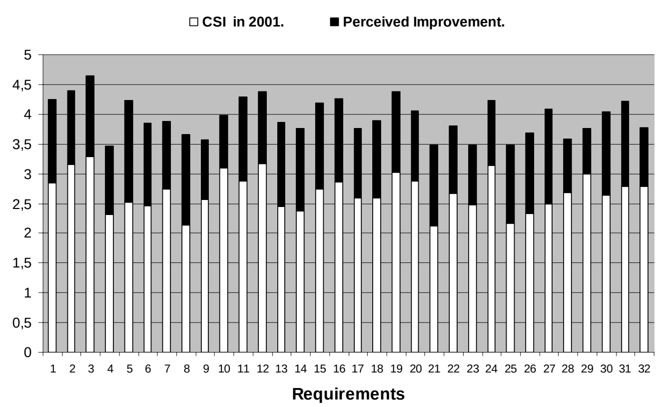

Figure 3 – Customer Satisfaction Index measured in 2001 and in 2006.

In Table 5 (column 2) we present the CSI grouped by the *Quality Dimensions* more valued by customers (see Table 3) and with the average CSI presented at the bottom of the table. As we can see, the overall CSI in 2001 was **2.69**. This means that, according to the previously presented scale, customer satisfaction is between Dissatisfied (2 points) and Satisfied (3 points), closer to Satisfied.

B. Measuring the CSI in 2006

Five years after starting the implementation of the *Characteristics*, many aspects have changed in the energy sector in general and in electrical power delivery in particular. Figure 3 presents, by the height of the columns (white plus black part), the expected improvements over each feature. As we can see, the black columns present the expected perceived improvement in each requirement. In Table 5 we show the same information, but grouped by the *Quality Dimensions* more highly valued by customers, where we can see in decreasing order the domains where a big improvement is expected to take place.

We can see also in Table 5 the expected Perceived Improvement by decreasing order of *Characteristics* impact.

TABLE 5 – IMPACT OF THE SOLUTIONS IN EACH QUALITY DIMENSION BY DECREASING ORDER.

Quality Dimensions	CSI 2001	CSI 2006	Perceived Improvement
2. Utility assumes more responsibility.	2.47	3.91	1.44
7. Differentiate the service to different segments	2.72	4.13	1.41
5. Technical auditing available to customers	2.25	3.59	1.34
1. Continuous improvement of quality product and service	2.90	4.19	1.29
4. Organization culture based on the obsession with the customer	2.66	3.93	1.27
3. Consider quality a crucial strategic vector	2,93	4.06	1.13
6. Decrease overall cost of product and service	2.73	3.81	1.08
8. Diversify the offer of services	2.79	3.77	0.98
Medium value of CSI →	**2.69**	**3.95**	**1.26**

We maintain the original order classification explained in Table 3 for each *Quality Dimension* in bold in Table 5.

C. Other complementary information

In Table 6 we present a small sample of information extracted from a Report produced by the *Council of European Energy Regulators* [14], where the evolution of some Power Quality indicators in several European countries, including Portugal, are displayed. As we can see, the trend of positive progress is more significant in the Quality of Service parameters.

TABLE 6 –QUALITY OF SERVICE INDICATORS IN PORTUGAL (2001-2004).

	2001	**2002**	**2003**	**2004**
SAIDI (1)	520	480	400	210
SAIFI (2)	7.5	7.4	6.0	3.7

Source: *"Third Benchmarking Report on Quality of Electricity Supply 2005"*.

(1) SAIDI (total interruption time in minutes per customer per year).
(2) SAIFI (total number of interruptions per customer per year).

VI. CONCLUSIONS

A QFD application to the electrical power delivery in Portugal was described in this paper. This work was developed in strong connection with the Portuguese utility company. The overall balance is strongly positive. Our main goal, right from the beginning, was to identify solutions with high levels of applicability. Through the results presented in section V we can attest the expected perceived improvements by customers, related to the improvement of quality in the product and service available five years after the beginning of the implementation of the characteristics.

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