An Analysis of Best Practices for DOT Traveler Information Data Quality

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Abstract
Data quality is a crucial consideration for the provision of meaningful traveler information. When drivers access traveler information that is up to date, correct, and accessible every time they need it, they will use it to make travel decisions which ultimately impact traffic management effectiveness and protect their safety. The goal of this project was to analyze and document existing system best practices for data quality for the aggregation and dissemination of state department of transportation traveler information. The research team conducted a survey of DOT practitioners in western states, as well as a literature review on data quality within the transportation field. "Best practices" were documented, and recommendations and next steps were formulated based on applicability to Caltrans traveler information data and processes. This work was sponsored by Caltrans under the auspices of the Western States Rural Transportation Consortium as a technology incubator project.

KEYWORDS: Traveler Information, Data Quality, Data Aggregation and Dissemination

Introduction
The transportation industry has shifted from building more infrastructure to "smarter" operation of existing roadways to better manage challenges such as congestion, inclement weather, maintenance, increased traffic volumes, etc. This shift has been accompanied by a rapid advance in technologies and an increased demand for more high quality, real-time traveler information. As discussed in a review of the state of the practice for traffic data quality from the Federal Highway Administration's (FHWA) first National Summit on Operations: "As more transportation agencies move aggressively toward system operations and performance measurement, the need for comprehensive quality data becomes imperative" (1,2).

Data quality for traveler information has generally been handled on an ad-hoc basis, with little or no provision for error notification other than perhaps through user-reporting of observed errors. The quality of data - for example, whether it is accurate, timely, and reliable - is a crucial consideration for the provision of traveler information. When drivers access traveler information that is up to date, correct, and accessible every time they need it, they will use it to make travel decisions which ultimately impact traffic management effectiveness (3). However, if travelers access traveler information and see bad data, then they are less likely to make travel decisions based on that information or even access it at all. This can significantly diminish the effectiveness of traffic management efforts and, if drivers use incorrect information to make travel-related decisions, more serious consequences may occur.

Background
The process of providing high quality traveler information that effectively impacts traffic management, safety, and operations, is complex and challenging. A core problem is determining which data quality measures to apply and how they should be used, e.g. determining what to measure and how to measure it. In September of 2000, ITS America and the U.S. Department of Transportation established guidelines for traveler information data collection and quality. In the introduction to the associated report, the authors

comment that the early vision for traveler information was simple – data would be collected by public agencies and disseminated to various devices and media outlets. However, "In hindsight, it is clear that the difficulty of collecting good, complete and timely data, transforming data into information, then packaging, marketing and communicating that information to people and devices was underestimated" (4). In the era of big data and rapidly changing technology, including the Internet of Things, this statement only begins to describe the challenge.

Data quality is a crucial consideration in the process of aggregating and disseminating meaningful traveler information. Potential issues and problems with traveler information data include but are not limited to: incorrect, erroneous or missing sensor data (temperature, precipitation, surface condition, etc.); bad meta data such as incorrect locations and timestamps; old, frozen, partial, poorly lit, poorly positioned or unavailable CCTV images; device settings visible to the public; etc. Following are several examples of problematic traveler information from the One-Stop-Shop for Rural Traveler Information (http://oss.weathershare.org/): In Figure 1, an Arizona DOT CMS message shows how a single missing letter dramatically changes the meaning of a message. Figure 2 shows a Caltrans CCTV image including configuration settings. The positioning of the camera makes it difficult to determine what is being shown. Figure 3 shows an incorrect pavement surface temperature from an Oregon Department of Transportation RWIS, indicating freezing conditions when freezing is not present.

Figure 1: Arizona DOT CMS Message with a Typo

Figure 2: Caltrans CCTV Image with Camera Settings

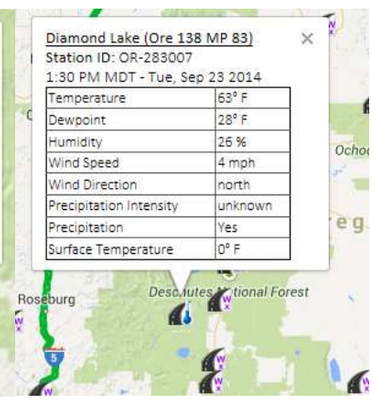

Figure 3: Incorrect ODOT RWIS Surface Temperature

There is a need for the development of best practices for data quality for the aggregation and dissemination of state department of transportation (DOT) traveler information. Taken individually, errors may seem anecdotal. But many errors are present at any time, indicating that there is a systemic problem that affects all state DOTs, with numerous points of failure. The goal of this research was to analyze and document existing system (best) practices for data quality for the aggregation and dissemination of state department of transportation traveler information. This work was sponsored by the California Department of Transportation (Caltrans) through the Western States Transportation Consortium (WSRTC). Caltrans has been working on the challenge of traveler information data quality relative to QuickMap (http://quickmap.dot.ca.gov/), the One-Stop-Shop (http://oss.weathershare.org/) and WeatherShare (http://www.weathershare.org/) , among many other projects. Based on this experience, it is believed that systemic problems exist regarding data quality and critically important issues need to be addressed.

Methodology

The research team conducted a literature search for best practices regarding quality control of traveler information data. To bound the task and adhere to the scope of work, the search was limited to providers closely related to traveler information. The research team then developed a survey asking DOT practitioners from western states about quality control measures employed by their state DOT and how data is handled

throughout the process from collection to dissemination. Contact was established with the person(s) responsible for traveler information in their respective state. The research team combined the results of the Literature Search and the Survey of DOT Practitioners. "Best practices" were then analyzed for applicability specific to Caltrans.

Literature Review

In November 2010, a final rule was published establishing the Real-Time System Management Information Program (23 CFR 511) in accordance with Section 1201 of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) (5). "The Real-Time System Management Information Program is to provide the capability to monitor in real-time the traffic and travel conditions of the major highways across the U.S. and provide a means of sharing these data with state and local governments and with the traveling public" (6). It provided a foundation for basic traveler information and data exchange formats and established minimum requirements for real-time traffic and road condition information for construction activities, road or lane blocking incidents, road weather observations, travel times, information accuracy, and information availability. It specified that a real-time information program is to be 85 percent accurate at a minimum or have a maximum error rate of 15 percent (7). But, no methods for measuring accuracy or other quality metrics were included. The program also did not define metrics for specific elements such as RWIS or CMS. Instead, individual states were given the "flexibility to use methods appropriate to systems and processes used to acquire information and data" (8).

In 2000, ITS America's Advanced Traveler Information Systems (ATIS) Committee published guidelines intended to aid public agencies and private firms in producing and utilizing data for traveler information. The guidelines addressed issues of content including type, coverage, and quality of the data (4). At the end of 2002, three white papers were published by the Federal Highway Administration's Office of Policy in support of a series of workshops on data quality to be presented the following year. A significant outcome from the FHWA traffic data quality workshops was a set of methods and tools for assessing traffic data quality. These tools included a sequential framework and guidelines for addressing "… technical issues related to the data quality standards, data sharing, estimates of the level of effort required for measuring and reporting data quality, and specifies procedures for using metadata" (9).

In the first white paper, Margiotta (1) characterized the state of the practice for traffic data quality from operations (urban TMC activities) and planning perspectives, pointing out that transportation agencies were moving towards system operations and performance measurement which made comprehensive quality data vital to both planning and operations activities. "Perhaps the best way to influence the quality of ITS-generated traffic data is to foster the development of more sophisticated operational response strategies that require more accurate and timely data" (1). In the second white paper (10), Turner recommended that traffic data quality be defined as "the fitness of data for all purposes that require it. Measuring data quality requires an understanding of all intended purposes for that data." Six quality measures were listed as essential to measuring data quality in traffic data applications: accuracy, completeness, validity, timeliness, coverage, and accessibility. Turner further recommended that goals or target values for these measures be determined at the jurisdictional/program level due to the significant variation in need and resources. The paper identified three traffic data consumer groups and summarized the data quality measures suggested or used in each of these groups. Some of these agencies/groups used simple data quality checks from field data collection hardware and software, tracked failed field equipment to measure coverage or completeness, evaluated accuracy of new equipment types before widespread implementation, and provided indication of data timeliness on traveler information websites (i.e., timestamps). A second group consisted of operations and users of ITS data archives including traveler information systems. Turner noted a general reluctance to use archived data due to data quality issues (real or perceived), adding that the field was in its infancy. However, some data quality processes/measures included data completeness (e.g., number of data samples in a summary statistic), data validity flags, data quality mapping utility, data validation checks (i.e.,

"business rules", software-based), and data integrity checks on data files and station integrity. As a final recommendation, if data quality is measured, Turner suggested a data quality report be included in metadata associated with the raw dataset. The third white paper presented techniques for enhancing data quality with quality control procedures (11). Of interest for traveler information applications, the authors discussed paying contractors based on data quality, standards development (i.e., for traffic monitoring devices), and detailed training for equipment and procedures. The benefits and value of sharing data between agencies and states were emphasized.

The effects of weather on the transportation system are well-documented in the literature. The Federal Highway Administration has dedicated significant resources to weather responsive traffic management to improve mobility, safety, and reliability of the transportation system during inclement weather. Traveler information is a key component in this initiative. Similarly, weather information is a crucial aspect of traveler information systems. In 2004, the FHWA Road Weather Management Program completed a preliminary gap analysis for weather information services and products for surface transportation users, operators, and maintainers (12). The authors found that weather data quality was not uniform – sensor siting criteria, test procedures, processing software, and multiple display formats were all contributing factors. Among other needs, "Rigorous standards for sensor siting and calibration, data validation, as well as data processing and presentation are needed to address deficiencies and inconsistencies in the quality of weather data used by transportation managers" (12). Pisano and Goodwin also identified research needs for weather-responsive traffic management that included how road weather information is delivered to different types of travelers (13). Baseline characterizations of road weather information were later established by Hart et al (14,15,16). The anticipated outcomes from ongoing monitoring related to traveler information included improved traveler advisory messages, improved responsiveness for implementing weather related traffic controls, and incentives for equipment and processing improvements for low quality resources (17).

The FHWA Road Weather Management Program launched the *Clarus* Initiative in 2004 with the objective of mitigating the effects of adverse weather (e.g., fatalities, injuries, delay) by providing nationwide, standardized weather data. The intent was "… to develop and demonstrate an integrated surface transportation weather observing, forecasting and data management system, and to establish a partnership to create a Nationwide Surface Transportation Weather Observing and Forecasting System" (18). The *Clarus* system itself was "a network for assimilating and exchanging *quality-controlled* environmental data related to surface transportation" (19). Data quality was an essential factor in the development and implementation of the *Clarus* System. One key component was that data flagged as anomalous through the quality control processing was transferred back to the source agency so that it could be further investigated, and issues could be resolved (19). Limber, Drobot, and Fowler describe the quality checking tests designed and implemented into the *Clarus* System in (20). Fowler et al (21) further describe and present test results on *Clarus* data for spatial quality control tests.

Around the same time the *Clarus* Initiative was kicking off, Canada also prototyped the Road Weather Information Network (RWIN) to enhance the country's highway system with improved maintenance operations, more accurate traveler information, and enhanced monitoring of conditions, among other goals. The RWIN was a centralized repository of data from provincial environmental system sensors (ESS) and instrumented vehicles. It performed "…Quality Control (QC) services, sending real-time alerts when deterioration or outage of roadside components [was] detected, and deliver[ed] quality-checked data in real-time to the Provinces, their agents, and their designated recipients in CMML [Canadian Meteorological Markup Language] and other formats" (22). Data quality checks were automatically performed based on predetermined thresholds for ESS and pavement data. All data were collected in a central repository which maintained ESS and instrument status reports and generated alerts. Data field statistics, including counts, frequencies, missing and extreme values, were available through a data auditing/profiling feature (22).

Other weather-related systems such as MADIS (Meteorological Assimilation Data Ingest System) (23,24), MesoWest (25) and the Oklahoma Mesonet (26, 27) have applied quality checks to weather sensor data, but these checks don't necessarily transfer to other sensor and data types. Further, these checks may not be applicable to department of transportation Road Weather Information System (RWIS) sites in the absence of data from additional sites. Some, including Caltrans District 2, have implemented measures of reliability based on network and file transfer performance. The District 2 Information Relay and the Caltrans Commercial Wholesale Web Portal (Version 2) (CWWP2) efforts have also included some checks for bad data in CCTV and other feeds. However, there do not appear to be unified, multi-dimensional approaches to data quality for aggregation and dissemination of DOT traveler information.

The Caltrans District 3 Regional Transportation Management Center (RTMC) implemented a weather alert notification system to provide timely traveler and road weather information particularly related to fog, wind, and frost conditions. Some findings and lessons learned are relevant to traveler information data quality (28). Regarding alert timeliness, alerts should be issued when conditions exceed the pre-determined threshold, or at the start of the event. The alert system helps operators post messages more representative of event duration. Operator training and clear, consistent procedures are essential. Operators "uniformly said it was critical to confirm either data from sensors with human observations or readings from other sensors, or human observations with sensor readings. This follows management guidance that all weather data be verified with one or more additional sources before making a decision to post a travel advisory message." Quality checking procedures such as those implemented in the FHWA *Clarus* system could be used to identify those sensors that were performing poorly. The FHWA ESS Siting Guidelines (29) could be used to determine preferred locations for collecting quality data. Regarding quality and timeliness of weather related decision making in the RTMC, one operator commented, "We are as good as the information we receive".

The Caltrans/WTI Phase 2 WeatherShare System implemented multiple levels of quality control for weather data including RWIS data. Perhaps the most useful quality control mechanism implemented in the WeatherShare project was user error reporting. Users were provided with a link to invoke a form that included a drop-box of typical problem types and an open text field that allowed for users to provide a description of the problem. Common problems reported included incorrect station locations as well as observations that did not match the known condition. Proactive monitoring of error reports and, where appropriate, responding to individuals who make error reports with resolution were considered necessary components of the user error reporting functionality (30).

The literature revealed a few studies and publications related to data quality for traveler information elements such as CMS, CCTV, and travel times. For example, in Minnesota DOT's 2012 CMS Manual of Practice, messages were to be verified through CCTV cameras or field staff, and operators were not to rely solely on electronic verification from the software/computer system. The CMS control software documented timestamps, message placement and termination (31). Chavan et al reported that overlaying travel time messages on speed plots provided a useful means of comparing sign messages with the actual travel conditions (32). Turner et al described procedural guidelines for evaluating the accuracy of traveler information including average route travel time (33). Others have presented techniques and methods for detecting anomalies or corrupted images from traffic cameras (34,35).

Many initiatives and research projects related to Connected Vehicle technologies have been conducted or are currently underway. One such project was the Vehicle Data Translator (VDT) software system. As envisioned by the overall Connected Vehicle initiative, the system was designed to incorporate "…vehicle-based measurements of the road and surrounding atmosphere with other weather data sources" (36). Numerous quality control routines were necessarily a crucial part of the VDT, and some were based on the quality routines in the *Clarus* system (36).

In general, concern for data quality is expressed throughout the literature regarding traveler information as well as operations and maintenance. The Federal Real-Time System Management Program established minimum requirements for data quality but left it up to the states and local jurisdictions to determine how to meet those requirements. A shift in the transportation industry to improved management of existing resources and infrastructure as compared to building more roadways has focused agency resources on performance-based metrics, which necessarily includes some treatment of data quality. This is evidenced in the literature relative to road weather management. Robust and continuous data quality procedures were fundamental to the operation of weather information systems such as *Clarus*. Other weather data systems also employ various quality control measures. Some documentation and research exists that addresses specific traveler information elements such CMS messages, CCTV, and travel times. However, while the literature documents a need, there does not appear to be any form of comprehensive plan for uniform, multi-dimensional traveler information data quality.

Other domains may have work relative to data quality. For instance, quality control processes used for security and surveillance may be applicable to CCTV or other traveler information elements. Documenting such work was outside the scope of this research project.

Survey of DOT Practitioners

A Survey of DOT Practitioners was designed to investigate the accuracy of data and metadata, what quality control measures are used, and how the data are handled throughout the process from collection to dissemination. Representatives from Alaska, California, Idaho, Montana, Nevada, Oregon, Utah, and Washington state DOTs participated in the survey. There was some agreement that the problem of data quality may be endemic. California/Caltrans specifically commented that they have no statewide defined procedures for data quality control and issue resolution. This is likely true for other states as well. While Transportation Management Centers (TMC) or 511 traveler information websites may implement some form of data quality control procedures, there did not appear to be a focused effort for data quality from the state DOTs. That is not to say that quality control is not being done at the state level, but rather in many cases it is being done ad-hoc based on the application or implementation.

The question of data ownership further complicates matters. The use of the data determines what thresholds are set and different users may have different thresholds. As one survey respondent said, “what one would call good data, another would call bad data.” There is also the question of where the DOT should sit in the traveler information environment. One state responded that the DOT has limited flexibility or ability to move quickly. This makes it challenging to quickly design and publish an app, for example, because it would already be obsolete by the time it was out for public use. In this case, the survey respondent indicated that the DOT’s “niche” may be to provide quality data to others and allow the traveler information environment to sustain it from that point.

With a few exceptions, we found that there is a general lack of automation for quality checking data that is used in traveler information systems. More automated processes could help with the obvious problems such as stale CCTV images or invalid sensor readings. Automated tools could also help to identify failing equipment that needs to be replaced.

There is variety among and even within states as to the type of traveler information data that is collected and made available to the public. This is due to many factors, including need, funding, and staffing. In some regions with fewer ITS resources, if a sensor is not reporting, it is just turned off. Some of the variety can surely be attributed to rural versus urban road networks, although that does not necessarily track directly to need. How traveler information data gets from the field to the public varies as well. For several states, data is collected at a district or local level and then input to a central system which in turn publishes it for public consumption. One state feeds all its data to a third-party vendor which in turn makes it available to the

public. A few states skip the local collection step and instead data goes directly to a central database system which publishes it for traveler information.

As expected, DOTs have experienced a variety of issues related to traveler information data quality including: CMS feeds issues (e.g., misspellings or typos, wrong abbreviations, multicultural challenges, sign limitations); equipment failure or end of life; cameras offline; communication, connectivity and power issues; old, partial or distorted images; incorrect location; old or stale information; inaccurate conditions reported; missing winter road reports; wrong dates on construction projects; operator input errors; sensor calibration issues; missing information regarding incidents, construction, lane closures, etc.

Quality control processes for traveler information data range from manual, to combination automatic and manual, to mostly automated. The level of automation is dependent on resources (i.e., staff, funding, etc.) as well as type and complexity of systems. Overall, manual quality control processes were more common, but survey respondents expressed or implied a desire for more automated quality control and/or indicated the state DOT was moving in that direction. In many cases, problems are identified by the traveling public who call, email, or use social media to report it. Depending on the problem, it is directed to the appropriate office or individual. How often manual quality control processes are conducted and by whom varies depending on resources as well as system type and complexity. In some cases, data is checked several times per day every day. In other cases, it is done once per day or one staff member is assigned to monitor the system weekly. In California, some manual quality checking is done in "responsive mode," for example, manual checks are done when a series of problems occur over a short period of time. Several states emphasized the importance of training for consistency and accuracy, particularly related to CMS messages.

Once a problem is identified and defined, the type of problem generally determines how it gets resolved and how long it takes to do so. In some cases, operators fix a problem directly (i.e., sign message misspelling) or take the element out of service while the problem is corrected. *Depending on the problem,* a work order may be issued, or the problem is handed over to a subject matter expert and/or a technician or vendor/contractor. Resolution could be completed within minutes while more complicated issues may take up to a week or longer.

Traveler information data control is a concern to state DOTs, with one state commenting that they "make sure that stale information is not presented to the public." Certainly, some proactive quality control procedures are utilized, particularly related to a handful of automated feeds. However, the traveler information element, system type and complexity, determine the level and form of quality control processes - ad hoc application of quality control. There do not appear to be unified, multi-dimensional approaches to data quality for aggregation and dissemination of DOT traveler information.

The state DOT representatives were asked to describe quality dimensions that their agency uses to assess system and site performance. Most states mentioned the Real-Time System Management Information Program (RTSMIP) (Section 1201 SAFETEA-LU, 23 CFR 511) (6,7) and the challenges associated with meeting its reporting requirements. The federal rule includes minimum requirements for traffic and travel conditions, but there are no specific metrics or definitions for data quality for RWIS or CMS, for example. As one state commented relative to quality dimensions and meeting the RTSMIP requirements, "This has been problematic - how to measure accuracy of … e.g., incident data … we're reporting what we know but how do we know if that's all." In other words, the requirements can be met, but if the quality of the information can't be quantified or defined, the requirements can be met with garbage data.

In general, no formal processes are in place to characterize system/site performance. "We are very short on metrics for traveler information performance measures," stated one survey respondent. Another state mentioned that public feedback is collected, and a public survey is conducted every two years. One state did respond that their DOT was working on performance measures across the organization and that data

quality was an important component of that program. They listed six elements for data quality: accuracy, accessibility, completeness, coverage, timeliness, and validity/reliability.

The state DOTs were asked about other quality control processes they are employing to ensure that field elements are operating properly and disseminating associated data as intended. Responses included verifying CMS messages with a CCTV camera; ground-truthing and sensor calibration; user reporting of errors; flagging questionable or bad weather sensor readings or posting a status message, such as "Image unavailable" or "Camera down for maintenance"; review of TMC logs and use of checklists during shift changes; multiple staff monitoring field elements; multiple camera images/views per site; tracking by contractor; periodic review and sampling; rigorous testing, calibration and preventative maintenance; among other responses. Most of the state representatives indicated future additions and improvements to their traveler information data and systems and/or said that they were "trying to improve."

Best Practices

Neither the survey of DOT practitioners nor the literature review identified a comprehensive, well-defined plan for unified, multi-dimensional approaches to quality assurance of traveler information. However, all DOT practitioners that were surveyed as well as the literature reviewed relative to data quality in transportation indicated that quality data was important for safe, efficient operation of the transportation system, including provision of traveler information. This observation is especially valid given the current environment that is increasingly focused on performance measurements, accountability and "smarter" operation of roadways, and is rapidly progressing with connected and autonomous vehicle initiatives.

Automated procedures could help to identify obvious problems such as stale CCTV images or invalid sensor readings. The more quickly a problem is detected, the more likely it can be resolved before it impacts traveler information. Automated tools could proactively help identify equipment that is failing or reaching the end of its lifecycle. Automated processing could also mitigate challenges associated with staffing resources (i.e., overloaded/understaffed). Status messages (e.g., "Camera unavailable.") should be posted or display should be precluded if data is flagged as erroneous. Timestamps should be provided with all data. Performance measures and standards for data quality, data validation, data processing and presentation, performance, maintenance, sensor calibration, and sensor siting should be defined and used. Data quality flags can be included with data if they are well-defined, accurate and meaningful. Reliability can be computed by compiling a database of outages and extrapolating percent up and down time.

Field elements should be rigorously tested before they are brought online. Laboratory calibration can help ensure that all sensors deployed are calibrated to the same high standards. Regular and adequate preventive maintenance, including calibration, for all field elements is essential. Maintenance resources and responsibilities can be shared. The ability to remotely calibrate sensors and restart systems are also useful tools. Statistics should be kept and analyzed to detect sensor drift, bias and other problems. Sampling techniques can be used if necessary. Checklists should be used during shift changes in TMCs, including a review of which elements and/or systems are up or down. Consider staff responsibilities (i.e., public information officer also tasked with traveler information quality control) and develop clear, consistent procedures for handling traveler information. Simplify manual data entry processes as much as possible. Spell checker functionality and a "public preview" options can be useful tools. Operator observations and human interactions are still important, even with automated systems. Training for consistency, accuracy, policy, procedure, etc. should be provided. And, user error-reporting mechanisms should be facilitated.

Where possible, operate traveler information systems and field elements redundantly to minimize the impact of outages and to provide multiple, overlapping sources of information. Use a central data aggregator/processing system that can consistently format (e.g., common format, uniform observational units, timestamps, etc.) the data for multiple uses and users.

Recommendations

Recommendations were made considering Caltrans' traveler information data and processes. Some of the practices identified in the previous section may be preferable to others, and some may only be applicable

in certain situations. It is recommended that preliminary steps be taken to establish a data governance model. This model should clearly define who owns what data, as well as uses and associated thresholds for the specified data. Relevant quality metrics and requirements should be clearly defined. This includes how to determine that requirements are being met with quality data. Common statewide standards for data quality, performance, maintenance, and calibration should be defined and established using an engineering approach. These standards should be tied to all specific uses of the data. There is a need to define where the state DOT is in the traveler information environment. And, it is recommended that implementation of additional automated feeds should be investigated.

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