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16. Abstract

Each year, thousands of utilities are installed within the Texas Department of Transportation (TxDOT) right of way (ROW). This proliferation of utilities makes it increasingly difficult for TxDOT to manage its own transportation system effectively and allow for more utilities. Research Project 0-2110 developed a prototype geographic information system (GIS)–based platform for the inventory of utilities located within the TxDOT ROW.

Implementation Projects 5-2110-01 and 5-2110-03 are the result of TxDOT's decision to implement the findings of Project 0-2110. Project 5-2110-01 focused on the implementation of the GIS-based utility inventory model, whereas Project 5-2110-03 focused on the implementation of the Internet-based utility installation notice review process (also known as the utility permitting process). This report summarizes the work completed in Project 5-2110-01.

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INVENTORY OF UTILITIES—SUMMARY REPORT

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DISCLAIMER

The contents of this document reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This document does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was Cesar Quiroga, P.E. (Texas Registration #84274).

NOTICE

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

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- Jesse Cooper—Right of Way (ROW) Division (implementation director),
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LIST OF ACRONYMS, ABBREVIATIONS, AND TERMS

AASHTO	American Association of State Highway and Transportation Officials
CAD	Computer-Aided Design
CSF	Combined Scale Factor
ESRI	Environmental Systems Research Institute
FHWA	Federal Highway Administration
GEC	General Engineering Consultant
GIS	Geographic Information System
GPS	Global Positioning System
ISD	Information Systems Division
NOPI	Notice of Proposed Installation
ROW	Right of Way
RTK	Real-Time Kinematic
SDMS	Survey Data Management System
SUE	Subsurface Utility Engineering
TGO	Trimble Geomatics Office
TSCe	Trimble Survey Controller
TxDOT	Texas Department of Transportation
UAR	Utility Accommodation Rules
VRS	Virtual Reference Station

INTRODUCTION

The large number of utility installations on the state right of way (ROW) is making it increasingly difficult for the Texas Department of Transportation (TxDOT) to manage the ROW effectively. Several factors contribute to this state of affairs, including the management of utility-related location and attribute data. The two main sources of these data are the Notice of Proposed Installation (NOPI) process—frequently called utility permitting—and the utility adjustment process. Both processes are paper and labor intensive, and they are frequently affected by data quality issues that prevent their effective use for the development and maintenance of utility installation inventories. With the deregulation of the utility industry, particularly in the area of telecommunications, there are now more utility companies that want to access the state ROW, resulting in additional paperwork and process management demands. Many TxDOT officials who have an intimate knowledge of where utility installations are in the field and/or the circumstances behind the accommodation of those installations are retiring or moving on, further impacting TxDOT's institutional memory regarding utility installations on the state ROW.

Research Project 0-2110 developed a prototype geographic information system (GIS)–based platform for the inventory of utilities located within the TxDOT ROW (*1*). Implementation Projects 5-2110-01 and 5-2110-03 are the result of TxDOT's decision to implement the findings of Project 0-2110. Project 5-2110-01 focused on the implementation of the GIS-based utility inventory model, whereas Project 5-2110-03 focused on the implementation of the Internet-based utility installation notice review process (also known as the utility permitting process). This report summarizes the work completed in Project 5-2110-01.

UTILITY INVENTORY MODEL

Project 0-2110 developed a simplified, prototype inventory model for utility installations. As part of the implementation effort, the researchers expanded and updated the utility inventory model to ensure compliance with a new GIS architecture at TxDOT. The updated utility inventory model included the following subject areas, which represent most utility features typically found on the state ROW: communications, electric, gas, miscellaneous, oil, sanitary sewer, steam, storm sewer, and water. The model describes a number of utility features associated with each subject area as well as feature documents that represent documents associated with each utility feature.

FEATURE CODES AND FEATURE CODE LIBRARY

Part of the implementation effort involved developing feature codes, sequence files for the American Association of State Highway and Transportation Officials (AASHTO) Survey Data Management System (SDMS®) environment (*2*), and a feature code library for the Trimble Geomatics Office™ (TGO) environment (*3*). Because most of the output from surveying activities feeds the production of Bentley® MicroStation® drawings at the department, part of the effort also included the development of utility feature cells for MicroStation use.

FEATURE CODES AND SDMS SEQUENCE FILES

Over the years, TxDOT has assembled between 400 and 500 feature codes that represent a wide range of features that are typically of interest to designers and surveyors. Some of the feature codes TxDOT has assembled over the years represent utility installations. In most cases, it was possible to map these utility feature codes to entities in the utility inventory model. However, there were also many cases where the utility data model included one entity to represent a specific type of feature on ground, but there were multiple feature codes representing the same feature, making those feature codes redundant. Eliminating redundant feature codes from the TxDOT feature code table was not feasible because of the likelihood that surveyors may have used those feature codes in the field. Retiring inadequate feature codes in future is a possibility provided there is an alternative set of feature codes. To address the limitations of the current feature code structure, the researchers developed new feature codes for all entities in the data model. To facilitate the use of feature codes in the field, the researchers developed a naming convention for feature codes where the first three characters of the feature code represent the utility class and the last three or four characters represent the specific feature of interest. For example, "SAN_MHOL" represents a sanitary sewer manhole. Similarly, "COM_JBOX" represents a communication junction box. For completeness, the researchers also developed a cell library to support the display of utility features in a MicroStation environment.

Parallel to the list of updated feature codes was the development of SDMS sequence files, which contain a list of attributes that should be associated with individual feature codes. For each feature code, the researchers developed a sequence file. The effort also included adding the new feature codes and data tags to the SDMS help file.

Developing feature codes and sequence files for the SDMS environment led to the following observations:

- Using two-character data tags to represent a large number of attributes per feature code in SDMS was challenging because of limitations in the SDMS architecture. Further, development of the new feature codes and data tags required close coordination with TxDOT officials to ensure the feature codes and data tags complied with SDMS structures and TxDOT requirements.

- To the extent possible, the data tags resembled the attribute name, e.g., "DI" in the case of diameter or "DP" in the case of depth. However, in many cases the data tags had very little resemblance to the original attribute names, e.g., "DY" in the case of construction method or "ES" in the case of encasement type. One of the problems with using data tags that do not resemble the features they intend to represent is that data collection becomes less efficient and more prone to errors.

- In the SDMS environment, it is necessary to use more data tags per feature code in a sequence file than the number of attributes associated with a feature class in the utility inventory data model. In addition, the fact that data tag value options must be included in the SDMS help file instead of separate look-up tables makes it difficult to manage those values effectively. The researchers found SDMS to be an unforgiving, old-technology environment that does not provide adequate feedback to users if it finds file content that does not conform to the default SDMS structure.

TGO FEATURE CODE LIBRARY

The researchers developed a utility feature code library for the TGO environment that contained the same number of feature codes as the number of utility-related feature codes developed for the SDMS environment. For each attribute, the researchers added a list of values to choose from during the data collection phase. As opposed to the SDMS file structure, a single TGO file contained both the list of feature codes and their corresponding attribute data tags.

Developing the utility feature code library for the TGO environment led to the following observations:

- The process to develop the feature code library is external to the TGO program file environment. This characteristic makes it highly unlikely that TGO or the data collection process would malfunction simply as a result of entering data tags or data tag values in an order that is not alphabetical. In contrast, the SDMS environment is highly sensitive to even minor changes in order and data tag names. Unfortunately, the TGO feature and attribute editor allows users to rename features but not attributes—users need to delete the affected attributes and then create attributes with different names.

- The TGO feature and attribute editor does not support imports from database or data modeling environments. This limitation makes it necessary to essentially replicate entire database structures by having to manually add every feature code, attribute, and list of values to the library. The interface does allow users to copy and paste features and/or attributes, but this functionality is limited to the editor environment.

- The TGO feature code library is compatible with Trimble® data collection equipment, which, in turn, produces global positioning system (GPS) data files TGO can understand and read. TGO can export survey data in a wide range of file formats. However, those file export options are limited. For example, TGO can export survey data to Environmental Systems Research Institute (ESRI) shape format (which is an old ESRI format) but not to geodatabases (which ESRI developed to replace the shape format and has supported for several years). Likewise, TGO can export survey data to MicroStation, but it only exports locations, not attribute data (or even feature codes). In the case of SDMS, TGO generates some basic location-related data tags, along with the feature codes, but not other attribute data tags. These limitations point to the need to develop customized data collection and processing environments outside of, or in conjunction with, the TGO environment.

TESTING

The researchers tested the utility inventory model using data from the Katy Freeway reconstruction project in Houston, which spans some 23 miles of IH 10 from Katy to Loop 610 and 3 miles on IH 610.

EQUIPMENT

Testing of the feature code library and SDMS sequence files involved the use of GPS equipment and a total station equipped with a Husky® data collector. The bulk of the testing involved the GPS equipment, with the total station testing (through a Houston District survey contractor) limited primarily to determining whether the SDMS sequence files worked satisfactorily in an SDMS data collection environment.

The GPS collection used for the testing consisted of three main components: a handheld Trimble Survey Controller™ (TSCe), a real-time kinematic (RTK)-enabled GPS receiver (Trimble R8), and a cell phone. According to the GPS manufacturer, the equipment can provide sub-centimeter horizontal positional accuracy. In reality, many factors can negatively affect positional accuracy. The cell phone uses a dial-up Internet connection to receive RTK differential correction data from the TxDOT implementation of a Trimble Virtual Reference Station (VRS™) network and then transmits the RTK data to the TSCe data collector via Bluetooth®. TxDOT has calibrated its VRS network for horizontal locations but not yet for vertical locations.

DATA COLLECTION

Data collection included locations with open trenches and locations where utility adjustment had essentially finished, and the features inventoried were aboveground appurtenances. To determine active job sites, the researchers relied on construction schedule information from the Katy Freeway project general engineering consultant (GEC) and TxDOT officials. Also critical were MicroStation files the GEC compiled for the entire Katy Freeway project that overlaid existing and proposed utility installations as well as ROW parcels on highway construction drawings.

Some lessons learned after the conclusion of the data collection phase include the following:

- Using an RTK-enabled GPS receiver facilitated the collection of differentially corrected GPS data in real time. This process translated into time savings because it was no longer necessary to first collect raw GPS data, wait several hours to download differential correction data back at the office, and finally conduct the post-processing calculations. As long as the cell phone received RTK differential correction data from the TxDOT VRS network and transmitted the RTK data to the TSCe data collector via Bluetooth, the equipment was generally able to produce differentially corrected GPS data.

- Despite the benefits of the RTK approach, the equipment used experienced a number of "problems" that made the data collection more challenging than originally expected. It is possible that some of those "problems" are related to the fact that some of the technologies incorporated into the GPS equipment were relatively new and, therefore, not as robust as older technologies the researchers had experimented with in the past. Some issues identified during the data collection include the following:

    - In some cases, the Bluetooth connection between the GPS receiver and the TSCe data collector or between the cell phone and the TSCe data collector failed and had to be reset. However, resetting the Bluetooth connection was not necessarily straightforward, involving in some cases rebooting the various components and following a lengthy procedure to reestablish the connection. Casual or inexperienced users would need a comprehensive set of written instructions to accomplish this task.

    - With the exception of an area in the vicinity of Katy, practically the entire length of the Katy Freeway project was within the reception area of the VRS network. Normally, if the data collection took place east of Beltway 8 there was no problem receiving good quality differential correction data. However, attempting to collect GPS data west of Beltway 8 frequently resulted in low-precision messages on the screen. The frequency of these messages increased as one moved west of SH 6.

Testing included interacting with GEC utility inspectors to determine whether a GPS approach could assist in the inspection process. Lessons learned from this activity include the following:

- Utility inspectors provided positive feedback concerning the data collection process, highlighting the potential benefit they could realize by collecting accurate positional data and relevant attribute data in an automated fashion. There were some hurdles, mostly related to equipment setup and initialization and general lack of familiarity with the equipment. Two features generated considerable interest with utility inspectors: staking out and automatic attribute data entry.

- Testing enabled the researchers to observe how inspectors manage specific situations in the field, such as inconsistent or irregular edges of pavement and inaccessible utility feature locations. Typically, inspectors confirm the location of utility features in relation to visible linear references such as the ROW line or the edge of the pavement by comparing actual offsets to theoretical offsets. The main disadvantage of this approach is that accuracy depends on the alignment of the visible reference, which could become critical if that alignment is not controlled or well defined. By comparison, measuring utility locations with a GPS receiver enables the calculation of differences in utility locations directly (i.e., between observed utility locations and theoretical utility locations), effectively bypassing the need to use non-reliable references on the ground.

- The field test also exposed challenges when using a GPS approach for utility inspections. For example, although inspectors learned the basic data collection procedure quickly, it would be advisable for them to receive additional training to fully realize the potential of the GPS approach. The researchers also noted that setting up the equipment could be time consuming, particularly for inexperienced users. System initialization, which is highly advisable to ensure acceptable positional accuracy results, can result in additional time delays. GPS-based data collection depends on adequate sky visibility, which can be challenging when attempting to take readings inside trenches or close to tall buildings. Data collection in trenches is possible but frequently requires indirect horizontal and/or vertical offset measurements, e.g., by positioning the GPS receiver at the top of the vertical trench excavation protection (where the sky visibility may be adequate) and by measuring both the width of the excavation protection and the vertical distance to the bottom of the trench.

GIS DATA PROCESSING

Deriving information from the field data involves using a file transfer utility to download field data files to a desktop computer, processing the data in TGO, and exporting data to a suitable format for further analysis. As mentioned previously, TGO can export survey data to MicroStation, but not feature codes or attribute data. To bypass this limitation, the usual process is to export the data in SDMS format, load the cell library and the SDMS-format data in Autodesk® CAiCE®, and then generate a cell-enabled MicroStation file. Notice that CAiCE can also accept regular SDMS data collected in the field (processed through SDMS Processor). An alternative to CAiCE is to process the SDMS-format data from TGO in GEOPAK® Survey™. To generate a .dgn file in this environment, it is necessary to use a symbology file that describes the graphical properties of each feature code.

While it is possible to link MicroStation to a database to enable feature querying and reporting, TxDOT does not normally use this functionality. As a result, most of the information collected in the field (except for feature code and one or two additional data tags) is actually lost during the data processing. Exporting the processed field data to a GIS environment is an option, although currently the number of business process data flows at TxDOT that support and use GIS data directly is still quite limited. This situation is likely to change as computer-aided design (CAD) and GIS vendors continue to develop tools to facilitate CAD and GIS data exchange and integration.

For this project, the researchers exported data from TGO in ESRI shape format, and then imported the resulting data into ESRI ArcGIS®. Because many of the data points were in active construction job sites, it was necessary to follow a number of steps, including loading shape files in ArcGIS; overlaying GEC-provided MicroStation files; conducting quality control checks on field data; generating geodatabase (point or polyline) records; and creating linkages between geodatabase records and supporting documentation, e.g., digital pictures taken in the field.

All the GPS data were in grid coordinates. Many of the GEC-provided MicroStation files were in surface coordinates, which required the use of a combined scale factor (CSF) to convert from surface coordinates to grid coordinates. In reality, the GEC kept a composite MicroStation file that included some 80 separate files, which resulted from overlaying files received from many different sources, including utility companies, consultants, and highway designers. Not all the MicroStation files, particularly those the utility industry provided, had survey control or were in State Plane coordinates. Therefore, to produce the MicroStation composite, the GEC had to manually transform (rotate, scale, or translate) several of the raw MicroStation files.

While the composite MicroStation file kept all the transformation operation information associated with each referenced MicroStation file, that information did not translate into the GIS. As a result, it was necessary to manually transform each MicroStation file loaded into the GIS. Depending on the coordinate system and relative position associated with each MicroStation file, the transformation included scaling, rotation, and/or translation. The result was a companion file, or “world” file with a .wld extension, that contained the necessary transformation parameters. For all the cases where the original MicroStation files were already in State Plane coordinates (and therefore the only transformation needed was scaling), the researchers normalized the process by creating a generic world file that contained the following data:

```
0,0 0,0
1,1 0.99987,0.99987
```

where 0.99987 = 1/1.0001300 was a TxDOT-provided combined scale factor for the Katy Freeway project area.

For all other cases, it was necessary to find suitable pairs of points and complete the transformation manually or with the help of a CAD transformation tool in the GIS (*4*). Strictly speaking, this process did not geo-reference files. What it accomplished was to produce world files that enabled a linear transformation of the data—made possible because the files were already projected to a rectangular grid to begin with—that, in turn, enabled what appeared to be the correct display of the MicroStation data in the GIS environment. The linear transformation was the result of combining three independent transformations—translation, scaling, and rotation—into one single transformation.

Some lessons learned at the conclusion of this activity include the following:

- The data model provides a mechanism for the development of comprehensive inventories of utility facilities on the ROW. Given the type and amount of information received from several sources (e.g., GEC-provided composite drawings and field data), the amount of attribute data collected was relatively low. For example, while it was possible to populate some basic information about manholes such as owner, cover type, and barrel material, completely characterizing individual manholes was not possible. Nonetheless, the expectation is that during the course of future subsurface utility engineering (SUE) activities, SUE contractors will be able to use the data model and associated data dictionaries and geodatabase structure to collect as much utility feature attribute data as possible or as TxDOT requires.

- The researchers used the data dictionary to collect utility facility data in the field and then used the data in combination with existing MicroStation files in the GIS environment. In many cases, it was possible to match the locations collected in the field with

MicroStation features. In other cases, there were discrepancies of several feet between GPS-based locations and MicroStation features. While it is possible that GPS errors could have been responsible for some of the discrepancies, a more likely scenario was that the MicroStation locations did not correspond to the actual locations on the ground. Surveying or stakeout errors aside, some utility company representatives indicated that the location of certain features on design and construction drawings, e.g., junction boxes, was only approximate and that the usual practice is for construction crews to determine the final location on the ground based on considerations such as actual cable lengths and need to avoid impacting other facilities in close proximity.

This realization highlights the need to always request as-built plans from utility companies. It also highlights the limitations of using design plans for the purpose of developing long-term inventories because of the uncertainty associated with the location of features depicted on the plans. This situation is particularly critical in cases where the design plans are not drawn to scale and/or do not follow appropriate quality standards. If the drawing does not rely on any type of survey control, it is up to the field crew to determine the final location of all the features on the ground. Frequently, the final location does not coincide with the location on the original design plans.

SPECIFICATIONS AND POTENTIAL CHANGES TO THE UAR

According to the latest version of the utility accommodation rules (UAR), codified in the Texas Administrative Code, utilities now have the requirement to provide design plans, construction plans, and as-built plans using the department's survey datum *(5)*. Title 43, Section §21.37 (c) of the Texas Administrative Code states the following:

> (4) Plans shall include the design, proposed location, vertical elevations, and horizontal alignments of the utility facility based on the department's survey datum, the relationship to existing highway facilities and the right of way line, and location of existing utilities that may be affected by the proposed utility facility.
>
> (5) As-built plans or certified as-installed construction plans shall include the installed location, vertical elevations, and horizontal alignments of the utility facility based upon the department's survey datum, the relationship to existing highway facilities and the right of way line, and access procedures for maintenance of the utility facility. As-installed construction plans certified by a utility or its representative shall be submitted to the department for each relocation or new installation. In the alternative, if approved by the director of the Maintenance Division or Right of Way Division, a district may require a utility to deliver either as-installed construction plans that are certified by an independent party or final as-built plans that are signed and sealed by an engineer or registered professional land surveyor. In determining whether to authorize a requirement for independently certified or signed and sealed plans, the director shall consider:
>
> (A) the amount of available right of way or the proposed utility facility's proximity to department facilities and other utility facilities that may be impacted; and
>
> (B) past performance of the utility in providing accurate location data and conformance with its certified as-installed construction plans.

TxDOT expects that, over time, these requirements will help to improve the quality of the plans and other documentation utility companies provide. However, from informal conversations with utility company representatives as part of a number of utility-related research initiatives, the researchers concluded that, as presented, the requirement information in the UAR is not sufficiently clear or detailed enough to allow the utility industry to comply with those requirements. Some of the areas where there may be a need for clarity include the following:

- TxDOT's survey datum. It is not clear how the utility company should interpret the requirement to use the TxDOT survey datum or the associated liabilities and responsibilities. While a land surveyor would immediately understand the implications of using TxDOT's survey datum, most utility company users do not have that type of expertise and might simply ignore those requirements. It would be advisable to modify the UAR to include survey datum in the list of definitions (Section §21.31) and include references to relevant documents such as TxDOT's Survey Manual *(6)* and construction specifications *(7)*.

- Relationship to existing facilities and structures. The term "relationship" is vague and therefore subject to interpretation. It would be preferable to include a more precise requirement that ties all measurements to the department's survey datum such as "The location, horizontal alignment, and vertical elevation of any existing or proposed feature on the plans, such as existing or proposed utilities, right of way line, right of way monuments, highway features, and roadside appurtenances, shall be based on the department's survey datum. Plans shall also be properly dimensioned and indicate horizontal and vertical offsets of the proposed utility facility with respect to the highway project baseline." To assist utility companies in this process, it would be advisable to always set ROW monuments on the ground prior to any utility design or adjustment activities and to provide relevant ground control data to the utility companies. Currently, although most districts set monuments for the ROW line prior to the production of the ROW map, some districts complete that activity during the construction phase.

- Access procedures for maintenance purposes. Currently this requirement is associated with the submission of as-built plans. It would be advisable to also include that requirement with the submission of design plans to allow TxDOT officials an opportunity to review the proposed procedures before construction starts.

- As-built certification. A limitation of the current requirement is that it does not tie the as-built certification requirement to the requirement to collect and maintain adequate supporting data during construction. In the absence of these data collection requirements, it would be very difficult for anyone (utility company, registered professional land surveyor, or registered professional engineer) to issue certified as-built plans, particularly in the case of underground utility installations, because the liability would be unacceptable. Under these circumstances, the only way certification is possible would be to conduct post-construction SUE investigations. It would be advisable to modify the UAR to include the requirement that as-built plans should be supported by location data collected in the field during construction. Further, field data should be part of the utility company's deliverables to TxDOT, should be compatible with TxDOT's utility data model and data dictionary architecture, and should use the department's survey datum.

- Design, construction, and as-built plan deliverable format. It is not clear whether utility companies should submit plans on paper or electronic format. Historically, TxDOT has allowed utility companies to submit plans in a variety of formats on different types of media. While this practice gives maximum flexibility to utility companies, the downside is that TxDOT utility coordinators, designers, and consultants end up with the formidable task of having to integrate disparate pieces of information into understandable composite files that, hopefully, overlay and show all the relevant features correctly. To address this limitation, it would be advisable to modify the UAR to include references to TxDOT CAD standards *(8)*. Notice that these standards are appropriate as long as users work in a MicroStation/GEOPAK environment. Because many utilities use other CAD platforms, e.g., AutoCAD, it would be advisable to develop guidelines for the conversion of other CAD files to the MicroStation environment.

- Amount of available ROW or proximity to TxDOT facilities and other existing utility facilities. Using this criterion to determine whether the director should request independently certified or signed and sealed plans can be confusing because terms such as "available space" and "proximity" are open to interpretation and depend on information that is not always available. Criteria that are more appropriate could include type and capacity of the proposed utility installation, which can be identified before construction starts.

- Section §21.37 (c) also includes the following text, which appears to be redundant and should be deleted.

> (6) If approved by the director of the Maintenance Division or the Right of Way Division, a district may require a utility to deliver plans that are signed and sealed by an engineer. In determining whether to authorize a requirement for signed and sealed plans, the director shall consider:
>
> (A) the amount of available right of way or the proposed utility facility's proximity to department facilities or other utility facilities that may be impacted;
>
> (B) the complexity of required traffic control plans;
>
> (C) whether the installation or adjustment activity requires a storm water pollution prevention plan; and
>
> (D) the utility's past performance in providing accurate location data and conformance with its construction plans.

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