DEVELOPING A SPATIAL DATA FRAMEWORK FOR MACAO

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ABSTRACT

Since 1990 the Macao Special Administrative Region (SAR) Government has been developing it's own Digital Cartography System, the predecessor of GIS. With the rapid development of infrastructures in Macao, efficient urban planning is essential in order to wisely use the scarce resources that are available. So GIS is a perfect tool for the decision-making process for the planning. Also, with the emergence and popularity of new technologies, such as the Internet, PDA's and wireless communication, the application of GIS is not only restricted to the traditional areas of application of GIS. The availability of information that conforms to the GIS requirement is essential to the suitability of the data for the above-mentioned application. A Spatial Data Framework based on accepted standards must be defined, so that information can be acquired based on this framework and make available to different kind of users.

In this paper, a Spatial Data Framework for Macao with the creation of a common data model specific to Macao will be proposed. Models based on well-known and accepted standards were studied and adapted to the specific conditions of Macao. Also, a proposal for future development of Web Services to deliver not only GIS spatial data, but also functionalities associated with these data will also be discussed.

KEYWORDS: Data Framework, Data Model, Geo-database, Spatial Data Infrastructure, Web Services

1. INTRODUCTION

Macao operates in the fast-moving, high-tech environment of the business world, in which jurisdictions are embracing and inventing the knowledge-based society. Simplification of processes, "one-stop" services, e-government, etc. are goals pursued by many governments. But still one of the most important in today's government top administration is decision-making. Nowadays, decision-making is no more a personal or leadership performance, but decisions need to be sound and based on information. But how can the management handle the overwhelming of information available to support their decision-making process? For decision-making in the Digital Age, administrators will all have electronic tools and information available to them. The provision of a robust GIS infrastructure and basis for working will allow decision-making to be undertaken within a rich information environment.

Since 1989 when the Macao government first introduced GIS in their work until the present day, GIS is getting acceptance in most major government departments of the Macao SAR government. This is even truer in the last few three to four years, with a big leap in the numbers of government departments approaching GIS for a solution to their problems.

The Macao SAR government Cartography and Cadastre Bureau (DSCC - Direcção dos Serviços de Cartografia e Cadastro) initiated the process of developing GIS in Macao since 1989. By then, the GIS technology was not yet well known in Macao, thus the work was focused mainly in digitising the existing base maps. All works were finished by 1993, with the entire base maps of Macao vectorized in CAD format.

At the same time, the work for building a cadastre database began. Re-surveying of most of the building and land parcels, collection and input to the database of parcels information were conducted. By the beginning of 1996, all the cadastre work was done and the boundaries of most of the parcels were confirmed with the land proprietor. In order to implement a cadastre GIS, a software was used to link the parcels polygon, as a CAD polygon, to the respective record stored in a RDBMS. Only the parcels layer was linked to the database through the creation of a centroid, the base maps were just used as an underlay beneath the parcels layer for reference purpose only. Thus, the software was some kind of an extension to a CAD system with capabilities to link to a RDBMS, and not a full-featured GIS.

In 1998, DSCC in collaboration with the Environmental Council (CA - Conselho do Ambiente), initiated a GIS project which purpose was for Macau's environmental impact assessment, and one component of this project was to develop a system that congregates all information related to the environmental monitoring, such as, weather information (temperature, humidity, wind speed, atmospheric pressure, etc.), air and water quality indexes, noise pollution index, etc. A web-based GIS system was established allowing users to browse environmental indexes through a common web-browser.

By the late 90’s, web-based GIS became very popular worldwide, thus DSCC also implemented it's own web-based GIS. The web-based GIS besides of allowing users to search for street names or building name through a common web-browser, also contains a rich set of “points of interests”, including schools, government departments, monuments, hotels, pharmacies, markets, museums, car parks, etc. This system was introduced to the public by the beginning of 2000 and got great acceptance from the public. Later, vegetation information was collected and incorporated into the web-GIS, thus allowing users to visualize and query for vegetation information for the whole area of Macao and its islands.

Later on, due to the advent of Mobile GIS, another project was initiated to implement a GIS development platform for PDAs over the Pocket PC environment. A first product developed over this platform is the “Macau GeoGuide” which was launched in September 2003. Map navigation, feature searching and geographic positioning are the main functions of “Macau GeoGuide”. In addition, a rich content of information and multimedia data are also integrated into “Macau GeoGuide”, such as, government departments, scenic spots, markets, memorials, museums, car parks, casinos, pharmacy, health centers, cemeteries, stadiums, hotels, gardens, churches, banks, police and custom departments, petrol stations, public toilets, cityguide kiosks, etc.

Other bureaux and utility companies in Macao also embraced to the GIS technology in order to increase their productivity or serve as support to their decision-making. Examples are, the Civic and Municipal Affairs Bureau for monitoring and maintenance of the sewage network, the Statistics and Census Bureau for spatially analyzing and reporting of census data, the Macao Electricity Company and the Macao Water Company for managing their respective electricity and water-pipelines network, etc.

From the above-mentioned projects, we can see that GIS is becoming widely used by Macao government departments and other organizations. With the success of some of the GIS systems, the administrators of the departments are becoming aware of the advantage of GIS as a tool for assisting in their daily tasks, the decision-making process, or just serving the general public with the most useful geographical information.

2. SPATIAL DATA

Although GIS is already used by several organizations in Macao, data is still widely dispersed over different organizations and no agreed upon standards exists for data interchange, so it is very time-consuming to collect all data and convert to a common framework to be used by specific applications. The reason is that many of the organizations developed their own GIS disregarding any future data sharing or a common data infrastructure issue. Thus, beside of using a common base map, i.e. a common geographical coordinate system, spatial data interchange between organizations will need some degree of conversion and rework.

In the past, organizations kept collecting data for their own needs. Either in manual form or more recently in digital form (or digitised), the data collection/input/maintenance process had always focused on the very own need of each of the organization. Here our concern is not in the availability of digital information, but on the awareness of organizations, which are producers of data, of the suitability of the collected data to other organizations. It is understood that many organizations had performed some level of standardization to their data, but most of these standardizations are very localized, having in mind only the needs of their own organization, without an overall concern to the applicability of the data by other organizations in present or in the future.

Without an overall picture of the available data of all organizations, resulted in that data produced by different organizations may have overlapping in part of the data, thus wasting resources of different organizations in collecting and managing the same data. Most of the time these data may not directly be usable by other organizations without modification, which involves unpleasant aspects of merging, transforming, overlaying and filtering information. Here modification doesn’t mean only the conversion from one data format to another, which can be accomplished with many commercial tools readily available (e.g. FME). Structural changes and adaptation will be necessary in order for an organization to use other organization’s data. For example, the census units used by the Statistics and Census Bureau were collected without considering the geometric elements of the cadastre parcels, thus both elements geometry does not match completely. Thus, in case spatial analysis needs to be done with both information, some work has to be done before in order to match geometrically the census unit with the cadastre parcels. Also notice that the match between both types of units is not one-to-one, but may be one-to-many or many-to-many.

The interchangeability of spatial data is core to the success or failure to the development of GIS in Macao, in view of the fact that GIS requires spatial data from different sources/organizations. The data from different organizations can be transferred, converted and reworked prior to insertion into the GIS. But one important issue that needs to be aware of is that each of the organization is the holder of their respective data, and they keep maintaining (updating) their own data. The frequency of update may be different from organizations, thus considering the maintenance of the data, it proves infeasible to establish a GIS that will need frequent repetition of the cycle for data transfer/conversion/rework in order to keep the GIS up-to-date, not to mention that an out-dated GIS is worthless. Consequently, preparing the spatial data so that the interchangeability between organizations will be possible without any conversion process in-between will be of utmost importance for the establishment of GIS in Macao. Through enabling the interchange of spatial data between organizations, decisions can be made with more thorough and more accurate information.

Even though there is a plethora of spatial data regularly being collected by government organizations and utilities, this data is yet to be made available through a spatial data infrastructure. Inter-organizational information sharing has become an important facet of the spatial data infrastructure. Through the definition of a common spatial data infrastructure, the interchangeability of spatial data between organizations can easily be solved. Every organizations which is provider of spatial data can adhere to the specification of the spatial data infrastructure for the data they are responsible. This way, during the data interchange process there will be no need for any kind of a priori data processing. The spatial data infrastructure can be seen as a common interface through which organizations can share their spatial data.

A first step in implementing a spatial data infrastructure in Macao is the definition of a common spatial data framework. This framework should be well-defined and based on well-known standards. Several standards are already proposed by national and international organizations, such as the US Federal Geographic Data Committee and the European ISO/TC211, which are the two major geographic standard committees. Besides of the government supported organizations, commercial GIS vendors and consortiums of public and private sectors also proposed their specific standards, such as the ESRI, Inc. and the Open GIS Consortium, respectively. Most of these standards are very similar in the sense that they provide a general framework for the implementation of Spatial Data Models. All of these standards provide the minimum requirements for the implementation of specific feature layers, e.g. base map, transportation, cadastre, etc. According to the particular requirements of each situation, adaptation and extension of the standard will be necessary to accommodate the specificy of each case.

3. FRAMEWORK FOR MACAO

From above, many of the organizations already have some kind of a GIS in operation. Consequently, these organizations also already have defined their own data model for the spatial data that they need for their everyday operation. One common problem in situations like this is the unwillingness to change, and it can be understood if we think of the chained reaction that changes to data model will bring to all other operations of the organization. This way, the data models to be proposed in the following sections will take into consideration as much as possible the existing data models.

The spatial data to be modelled will be the major categories of themes that exist in Macao: base map, cadastre, administrative boundaries, transportation, utilities, sewage and environmental. These data models will be based on the existing data and the requirements of the interrelated organizations. A sound infrastructure needs some harmonization for optimised common use of services and data provided.

3.1 Spatial Data Model (SDM) - Base Map

As described earlier, the base map of Macao was digitised during 1989 to 1993. By then, the main concern for the digitisation process was just to convert the existing paper maps into digital form. The processes can either be rasterization followed by vectorization of existing paper maps or, with more accuracy, obtained from stereo-plotting of aerial photography. Consequently a CAD system was used and by 1993 all the base maps were already digitised in CAD format. Maintenance of the CAD drawings (i.e. editing) and plotting were all performed in the CAD system. Following that the main purpose of the base map was just to plot paper maps, focus was placed on the appearance of the maps rather than the information suitability of the base map if used in a GIS.

From experiences of other places and the development of GIS by mapping agencies during the last decade, we can understand that many of the mapping agencies also committed the same oversight, thus the popularity of CAD based GIS system in the early 90’s (e.g. Autodesk Map, Intergraph MGE, etc.). But will this hamper the usability of the existing base map in GIS?

Every GIS project has a base map, either it is for cadastral purposes or transportation purposes or environmental purposes, etc.; the base map is used to provide a geographic context to the GIS project to enhance the cartographic presentation of the data. A base map is composed by a set of map layers organized into a logical presentation for a specific map scale. A specific geographic coordinate system and map projection is defined for the base map, which can also be a work base for all other kinds of GIS project. In this way we can see that there is not much database design involved in the definition of a base map data model for GIS projects. Therefore the design of the base map data model involves mostly an analysis of the common themes and classes used by different GIS projects. Owing to the spatial reference purpose of the base maps, the data model will simply be the collection of layers with topographic information of interest.

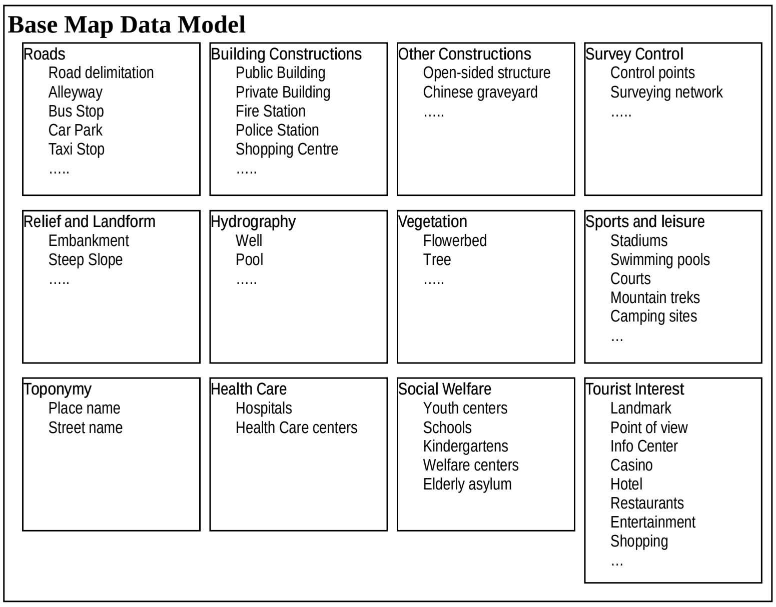

Figure 1 - Base Map Data Model

3.2 SDM - Cadastre

National governments are important sources of regulations for cadastre. The US and the European Union both published standards for Cadastral Data - the Federal Geographic Data Committee - ANSI Cadastral Standard (now in version 1.3) [FGDC 2003] and the ISO/TC211 (http://www.isotc211.org).

By FGDC definition, Cadastral data describe the geographic extent of past, current, and future right, title, and interest in real property, including above, surface and below ground and water, and the foundation to support the description of that geographic extent. But this definition has slight variations within different countries, and the contents to be registered in the Cadastral database may be quite different from places to places. Even the land registration system has very different variants (e.g. deed system versus title system).

Although the differences in cadastre from various places is great, the description of the structure of cadastral data bases by using FGDC or ISO standards will still be helpful in applying these global standards to a definition of a minimum content of a cadastral data base and later "tailoring" the database to the specific requirements of a particular place. Thus, both standards is similar in their advantages to serve as a basis for automating and organizing the elements of cadastral data found in land records.

In order to ascertain land parcels limit and to provide support for organizing and planning of real estate properties in Macao, DSCC started a systematic on-site survey of all land parcels in Macao since 1983. Precise land boundary limits and area values are obtained by using advanced surveying techniques. At the same time, relevant cadastre data was also collected, such as land title description from the Land Registrar, taxation records from the Finance Bureau and a descriptive location of the land parcel. After the 10 years of work, a cadastre database of the entire Macao was established. From September 1994 to February 1998 a campaign, called the *Cadastre Publication*, had taken place in order for the landowners or the relevant people to recognize the land demarcation, proceeding to the review of the cadastre plans, claim oppositions or request for modification to the plans [source: http://www.gis.gov.mo/dscc/engl/newnotice1.htm].

The geometric layout of the cadastre system of Macau is structured in a hierarchical tree. At the top level, the natural boundaries of Macau peninsula, Taipa island and Coloane island define the three large cadastral *zones*. Under these three zones, seven administrative boundaries are defined - the *parishes* - five in Macau peninsula and one each for the two islands. Then, under each of the parishes *quarters* are defined which are agglomerates of *land parcels*.

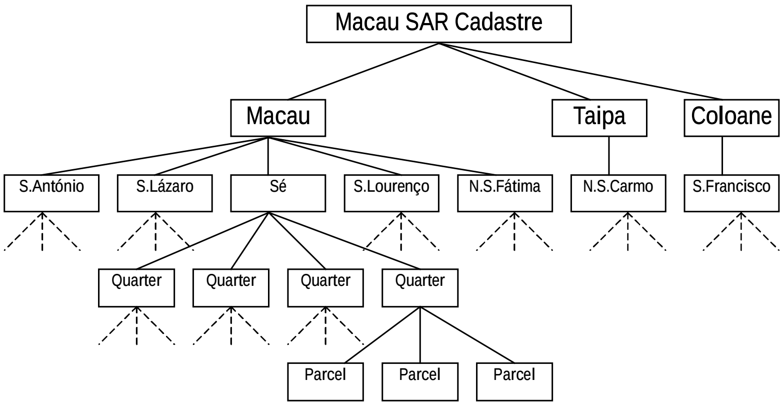

Figure 2 - Hierarchical Structure of Cadastre Model

Using this method, data sets of different features boundaries can be made to match allowing spatial analysis to be performed over several features. At the lowest level, we have the land parcels which depict a building or a piece of land, and attribute information for cadastre is attached to each of these parcels, such as, cadastre number, land registration number, taxation information, ownership, area, description of location, etc. One level up, we have the quarters, which are collections of parcels. The quarters are made so that they should match with the census units (see Administrative Boundaries below), thus allowing overlay analysis between both features. The match proceeds upwards, to parishes' boundaries and natural boundaries.

3.3 SDM - Administrative Boundaries

Organizations, in a way to better manage administrative, political and economic activities had segmented and structured the spatial environment in various ways to meet individual needs. To date, the majority of spatial boundaries have been constructed in an uncoordinated manner with each organisation generating individual boundaries that may not match other organizations boundaries. This practice has resulted in boundary layers that are difficult to be overlaid and cross-analysed by GIS. For example, the health care centres coverage area may not match the fire department's fire station coverage area. Thus, it may happen that an ambulance from a fire station may not deliver correctly a patient to the correct health care centre.

With the advancement in GIS technologies and the possibility to overlay different layers of information and perform some cross analysis, this analysis ability becomes even more crucial. Therefore the necessity to define a spatial framework for the administrative boundaries, so that all organizations can adhere to the same set of boundaries.

In Macao, we can define a hierarchy of boundaries from the following model:

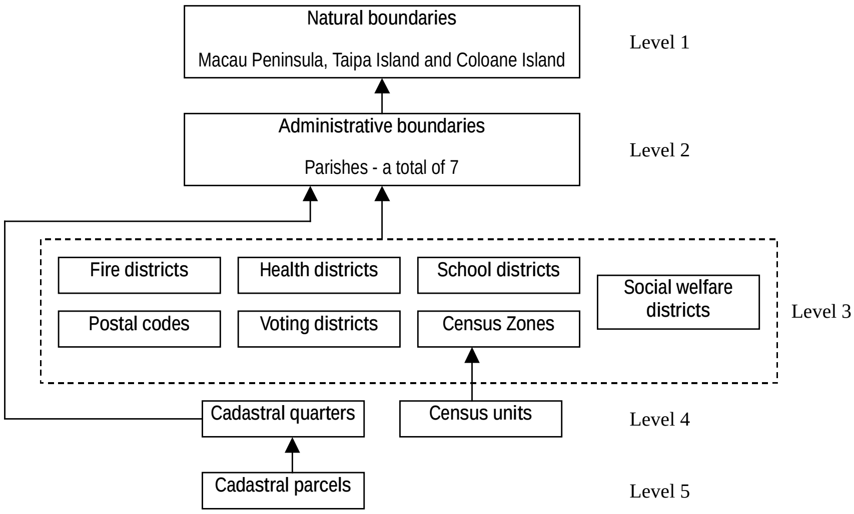

Figure 3 - Hierarchy of Administrative Boundaries

By defining a hierarchical structure to the boundaries, which higher level boundaries (e.g. level 1) will be formed through the aggregation of smaller units from lower level boundaries (e.g. level 5), most of the problems associated with incompatible boundaries will be solved, as organizations should adhere to the hierarchy of boundaries. This way, it will enable rapid and efficient cross analysis between data sets provided by different organizations.

The most detail subdivision will be at the parcels level, although due to the confidentiality of some data (e.g. census) not all types of boundaries can be subdivided into individual parcels. But this does not apply to the inverse, as the aggregation of parcels can yield a particular administrative district or zone. Thus these two limits should be made to match. The match should also apply further up, as for the aggregation of particular districts should match the parish limits, and the aggregation of parishes should match the natural boundaries.

We have seen that, matching boundaries vertically in the above hierarchy does not turn out to be a problem. Then, how about horizontally? That is, will we require the boundaries of, for example, fire districts to match with that of the school districts? The answer is that it is not always possible and not necessary. Many GIS techniques exist for solving this kind of problems, such as, data interpolation, data aggregation or redistricting.

In spite of the existence of such techniques, it would be desirable that the parcels quarters and census units' boundaries should match, as the number of elements from these two data sets is huge.

3.4 SDM - Transportation

Transportation data modelling standards usually comprises three components: the development of conceptual object model of transportation features (e.g. networks, directed graphs, etc.); the incorporation into the system of multiple modes of travel (e.g. road, rail, aviation, etc.); and the accommodation of multiple scales of interpretation of the real world (e.g. a road can be represented as a road segment, by traffic directions or by each of it's lanes). The transportation data modelling standards, besides of dealing with transportation infrastructures, including roadway and railway network features, etc., they also as well deal with the interaction between the infrastructures for modelling intermodal transfers.

Although many models and formats exist, such as, TOP (Transport Object Platform), GTF (Generalised Transportation-data Format), TRANSMODEL (CEN-norm prENV 00278021), etc., three major standards are used widely for GIS-T:

- the UNETRANS - the Unified NEtwork-TRANSportation data model, which is a collaborative project between ESRI, Inc. and the University of California, Santa Barbara (UCSB), to develop a generic data model for transportation applications, using ESRI software;
- the FGDC NSDI Framework Transportation Identification Standard;
- and the ISO/TR 14825 GDF (Geographic Data Files), now in version 4.0 (http://www.ertico.com/links/gdf/gdf.htm).

GDF was developed mainly for road traffic and has a higher degree of pre-definitions than UNETRANS. Although GDF is more a format, and UNETRANS a model, their underlying conceptual models have similarities, as GDF was reviewed before defining UNETRANS. But, the GDF standard has much in common with the UNETRANS data model. Both are based on a general, non-application specific data model with the intention that specific applications can be built from the basic elements. The UNETRANS model differs from GDF in that it is intended to apply to transportation activities modelled exclusively within a GIS, while GDF has a broader application.

CEN - Comité Européen de Normalisation (the pan-European standardization body) and ISO is working on the GDF standard, it is also becoming a de facto international standard, with several national standards for intelligent transportations moving towards compatibility with GDF, while GIS vendors, such as ESRI and SmallWorld, have developed GDF interfaces for importing GDF files into their internal data models.

At first glance, designing data models for Transportation may not appear difficult. In contrast with many other GIS applications, Transportation has a central object of study, namely, the Transportation Network in a study area. However, digital representation of these networks is not easy. Transportation network data is complex since it is often multi-modal, exists across many different jurisdictions and has different logical views depending on the particular user. There is often a need to reference events (e.g. accidents, pavement quality, road blocks, etc.) within the network. A network can have varying representations depending on the map scale of interest. There is often a need to represent the relationships between the network and other non-network data. Advanced transportation applications of GIS require the ability to track conditions or objects over time as well as solve navigation problems, like finding the best route [Miller 2000].

In Macao, a special situation arises as only road transportation exists at the moment (i.e., no trains, undergrounds, etc.). In order to establish a high efficiency and effective road transportation GIS in Macao, it is necessary to firstly introduce an also efficient and effective road network data model for the road network of Macao.

The Macao road transportation should be best represented as a Planar Network, which is a type of graph, i.e. a node/arc representation. An important difference between a network and a graph is that a network can accommodate weights associated with each arc. Each arc has a *weight* that represents the cost incurred by one unit of flow when traversing the arc. The model of our road network mainly depends on this node/arc data model structure. Being a planar graph, in order to prevent a vehicle from flowing between different levels through a node, additional attributes must be stored in each arc (e.g. a start, main and end level) to enforce the connectivity for the same level through an arc.

Another consideration for our road network is the direction of flow. In the basic node/arc representation, we deal exclusively with directed networks (that is, a network consisting of directed arcs) since road network models typically have important directional flow properties (e.g. one-way streets, differences in directional travel times depending on the time-of-day, etc.), although how the direction is represented or dealt depends on the system implementation. For a road network, nodes generally correspond to road intersections while arcs correspond to road segments between intersections. Generally in a node/arc representation we distinguish two types of directions, a digitised direction which represents the start and the end of a line during digitisation (i.e. data collection/input), while the traffic direction represents the real world movement of vehicles. For the digitised direction, it contains only one direction from start to end. However, the traffic direction has cases of one way, two ways or close for both directions [Brilliant 2002].

One factor, which is associated with the direction of flow, has to do with the level of detail to represent the traffic flow. The level of detail to represent the traffic flow has direct influence in the data model we adopt for the road network. Three data model representations can be differentiated according to the level of detail of representation of the traffic flow - road model, direction model and lane model. The *road model*, which is the less detailed representation, traffic flows are only represented with one arc for the road disregarding the directions (one-way, two-ways or more) or the number of lanes. In the *direction model*, one arc is used for representing one direction of the traffic flow, although the number of lanes is not distinguished in this representation, i.e. even there are more than one lane in the same direction, only one arc is used representing all the lanes in the same direction. The most detailed representation is the *lane model*, which every lane of a road is represented with an arc [Ho 2000].

Following the geometric representation of the network, the next part concerns with how we manage the *routing* and *location referencing*. One of the important features in managing a road network navigation is the turn. In the reality, turns appear in each intersection to indicate a vehicle movement from a road element transacting to another road element. In a database, *Turntables* are used for storing data on expanded intersection representations in a 'from arc- at node- to arc' pattern. The turntable contains a tuple corresponding to each direction of travel through an intersection. A reserved character (IMP) can indicate a turn restriction, e.g. if the turn is possible, the 'IMP' value would be 1, otherwise is 0. An optional field maintains the travel cost associated with that direction of travel/turn (or perhaps a pointer to a flow cost function) [Brilliant 2002].

With both the geometric network, which the direction of the traffic flow is defined, and the turns information, operations such as finding the optimal path can be performed over the Road Network.

Further enhancements of the Transportation Data Model can include peripheral information related to the network. These include: traffic lights, road signs, separators and guardrails, parking lots, etc. Usually these information are defined as *assets* of the transportation network. Another type of information related to network has to do with the dynamic behaviour of the network, such as blockage of part of the roads. These blocks are temporarily, but can be foreseen or unpredictable. Activities such as construction works or road maintenance may involve the temporary closure of lanes or an entire segment of the network, which is known in advance. When the construction is completed, the road will return to its initial state, and the activity and its related attributes may be stored for historical purposes. On the other side, some unpredictable incidents may occur along the transportation network which are not planned in advance. Occurrences such as traffic accidents, spills, fire are examples of incidents that may require a temporarily closure of a lane or a road segment. These closures will have impact over the routing procedures, but only momentarily during the closure. After this period of time, the incident no longer directly influences network processes, yet the incident may be preserved in the transportation database for planning, enforcement, and safety reasons.

3.5 SDM - Utilities, Sewage and Environmental

GIS have, over the past few years, become more widely used in utilities/sewage/environmental areas, improving operation efficiency and service quality. Even though, standard for spatial data specification is not widely used. The reason for this is that even the own standards in these areas differ widely from places to places. For example, in the electricity distribution network, different countries apply their own standards, which is comprised by a set of standards for the equipments, the network elements, cabling, etc. In the environmental area, the same happens, as different places have different kinds of environmental facilities, and some of these may not be used or available in other places.

Only three major utilities exist in Macao, namely, electricity, water supply and telecommunications. Each of the utility have their special characteristics, for example, the electricity company has under it’s management not only the power plants, but also the distribution network, which is composed of power lines, substations, power lines joints, relays, transformers, etc. The water supply company have to their responsibilities the reservoirs, the transmission network, which is composed by aqueducts, tunnels, pumping devices, etc.; and the distribution network, which consists of pipelines, pumps, treatment plants, etc. Finally, the telecommunication company must handle the cablings, dispatching devices, mobile phones transceivers, etc. Due to the very particular characteristics of the entities that utilities companies need to manage, specific data modelling were adopted by these utility companies, although a same reference were used by these companies based on DSCC’s specified geographic information.

One special situation in Macao is that the sewage system is managed by the government and not by private companies. The Civic and Municipal Affairs Bureau has to its responsibility the management of Macao’s sewage system. Due to historic reason, Macao’s sewage system is a combined sewage system, which means that wastewater, from home and business, are intermixed with storm water. In recent years, because of environmental reasons, wastewater pipelines from major industrial areas are being built to convey waste water to water treatment plants for treatment before disposal to the sea. As a consequence, the model should be aware of future improvements of the sewage system, mainly the separation of waste water system and storm water system. Both systems are based on network, specifically a radial network - flows always have an upstream and downstream direction that branches out/in. This is in opposition to a looped network of most water supply networks, which flows frequently self-intersect, to ensure the lowest interruption of supply to customers.

Other features that need to be inventoried for a sewage system are gutters, catch basins, ditches, culverts, manholes, valves, pumping stations and tide-gates. All these can be modelled as point features relating to the sewage network.

In Macao, environmental related features can be divided into two major groups. One groups the entities whose businesses may have the potential to cause environmental pollution, such as, restaurants, factories, dry-cleaners, hospitals, petrol stations, etc. The other groups facilities for monitoring environmental conditions and treating environmental wastes, such as, air pollution monitoring stations, weather monitors, waste water treatment plants, landfills, etc.

Permits for the operation of certain businesses as mentioned above are issued according to the entities meeting specific environmental standards. One of the responsibilities of the Macao's Environmental Council is to keep records for these businesses and continually inspecting these businesses whether they are meeting previously set environmental standards. Consequently, this group of themes can be simply represented geometrically by point features, registering each entities locational information, besides of other general information (e.g. ownership, type of business, type of environmental waste that produces, tax for waste disposal, etc.).

On the other hand, facilities for monitoring environmental conditions and treating environmental wastes are more complex to be represented geometrically. Some entities can be represented as point features, such as, different types of monitoring devices (e.g. air pollution, water pollution, noise, weather stations, etc.). These devices only records observations and stores the data into databases for analysis purposes or for calculating specific indexes. Other can be represented as polygon features, such as, landfills which the delimitation of the landfill area is important for keeping track of the expansion of the area. But, there are some entities that need a more complex representation of its geometry; an example is a wastewater treatment plant. Besides of the need of representing the plant itself, which can be represented as a point or polygon feature, there is also the need to represent the transmission pipelines, which should be line features.

4. FUTURE DEVELOPMENTS

4.1 Mobile Technologies

The phenomenal growth of Personal Digital Assistants (PDA) and wireless technologies (such as Wireless Application Protocol (WAP), General Packet Radio System (GPRS) and Universal Mobile Telecommunications System (UMTS)) in the 21st century has paved the way for GIS to adopt the mobile technology. Mobile GIS has recently gained a strong foothold in many areas, owing to the ability to carry into the field the power of GIS. In today's fast-paced world, who wouldn't want to possess an overwhelming of information and services literally delivered to their fingertips? Porting processing-hungry applications like GIS to mobile phones or PDAs will present several challenges.

But the ability to provide users with on-line information, such as, schedule of activities (e.g. performances, theatres, seminars, sport events, etc.), transportation schedules, weather information, etc. directly to their "hand" regardless of their present location, and even helping users to locate themselves, will be next great step on the proliferation of the usage of GIS. The main obstacle in providing spatial information through mobile devices at the moment is on the infrastructure, namely few people have PDAs equipped with GSM modem, wireless LAN (WLAN) or Bluetooth, and also GSM connections are still quite expensive. Due to the small size of Macao, one economical way to overcome the problem is to establish WLAN access points at places most frequented by people (e.g. airport, pier, bus stops, tourist information centres, etc.). It is hoped that in the near future, this technological obstacle will be overcome.

4.2 XML-based Web Services

Over the last few years XML-based web services were widely adopted in the software industry. XML is the universal language for data exchange between machines, allowing data sharing regardless of the computing machine, the underlying communication network, the operating system, the network protocol or the programming languages. As XML is an open standard supported by all major operating systems, development tools, and platforms, XML web services enable communication between previously disparate systems. Also, applications are constructed using multiple web services from various sources that work together regardless of where they reside or how they were implemented.

Then how the implementation of GIS, and specifically the mobile GIS, would benefit from the application of XML web services? In Macao, as in elsewhere, spatial data sets are maintained by different organizations. A problem that is usually encountered is that a new set of spatial data needs to be maintained for the each GIS platform (e.g. desktop, mobile, Internet). Also, when updates of the spatial data sets are performed, it has to be aware of the different platforms available. Alongside the data maintenance problem mentioned above, supporting different applications on several platforms using a variety of development environments (e.g. desktop, web-based, PDA, mobile phone) would consume unnecessarily many resources.

The advantage of XML web services is that, by establishing a spatial database server and delivering GIS functions as XML web services will allow users access those spatial data seamlessly or even to build new and more powerful applications that use XML web services as building blocks. Thus, either the user is accessing through a web-browser on a desktop, or through a PDA or mobile phone across a wireless connection, there is no need to establish and maintain distinct sets of spatial data for each of the platform and the same set of data resident in a server will be delivered to the user. In a programmer's point of view, with XML web services as software services exposed on the web through SOAP, described with a WSDL file and registered in UDDI, they can easily incorporate these services in their applications independent to the development tools used or the platform on which it is executed given that these applications can communicate with each other in a standard-based way [Wolter 2001].

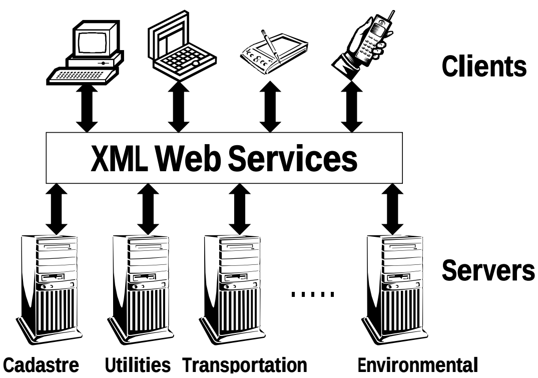

Figure 4 - XML Web Services

Another advantage in deploying XML web services is that multiple servers can be set-up. Spatial databases are usually managed by different organizations and stored in different data formats resident in the organization's database servers. Seamless exchange of spatial data can be accomplished by each organization making available their spatial data and functionalities through XML web services.

Thus spatial data maintained by different organizations can be made available as XML web services through their respective spatial data servers and, consequently, the application programmer can simply use these web services as building blocks for any specific application build on PDA, mobile phone or just web-browsable. In the users point of view, he/she does not even know that the data provided by the application he/she is using is an aggregate from various sources [Gracias 2003].

5. CONCLUSION

Having seen each of the components for a spatial data framework for Macau, then what will be the benefits of establishing this framework in Macau? The development of this Spatial Data Framework is expected to bring about various types of direct and indirect efficacy, as follows:

- Effective utilization of resources used for servicing of spatial data
- Systematisation of information management based on a platform of spatial data
- Support to the decision-making process
- Availability of spatial data whenever necessary
- Data integration/exchange
- Distribution of roles and responsibilities between participating organizations
- Optimisation of resources required for the maintenance of spatial data.
- Spatial data will foster the creation of new businesses

There has been great optimism about the potential of information and communication technologies in revolutionising the use of spatial data. The convergence of wireless communications, positioning technology (e.g. GPS) and computer networking is now capable of providing new facilities, new applications and as a result, new challenges for spatial data providers and users.

Wireless access to data is a rapidly emerging field, particularly with the recent advancements in the wireless technologies (e.g. WAP, GPRS and UMTS). Wireless communication is inherently linked to location, and already many wireless providers are using GIS to supplement their services to clients. Relevant information, with respect to time and location, can now be delivered to users via devices such as mobile phones and PDAs.

However, the infrastructure requirements for wireless applications that utilise spatial information need to be determined and integrated into the future design of a spatial data framework so that they may reflect and support the changing nature of spatial information use. Many applications already exists that use and/or deliver spatial information to mobile users, however none of the applications currently access data through an established framework. Rather than individual organisations duplicating and maintaining their own data sets, accessing them through some standard frameworks would be most beneficial and would ensure that fundamental data sets would remain the responsibility of the data providers. Naturally, different applications will have varying spatial data usage requirements, however a common and unique repository of spatial information, such as a spatial data framework, will provide the infrastructure elements (such as query and delivery mechanisms) for a range of applications. This will have the benefit of resource sharing and avoiding data duplication.

The opportunities created by web services are immense and it is likely to have a far-reaching impact in the establishment of a framework. Organizations can make available their respective spatial data and functionalities as web services. Topo-cartographic, tourism, transportation, environmental, utilities, sewage, cadastre, etc. all can be delivered as web services. The problem of sharing and transferring data between organizations can easily be overcome by adopting web services as a kind of data exchange standard [Gracias 2003].

The user will be able to access all the spatial data and functionalities from different providers in a seamless environment. Thus, either the user is using a desktop internet browser, a tablet PC, a PDA, a mobile phone or any other mobile device, there is no need to implement specific applications on each of these devices, because of the cross-platform independence of XML web services. All of these benefits can be applied from the creation of a spatial data framework for Macao, thus providing the same platform, network and application independencies.

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