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Spatio-temporal Modelling in GIS

— The impact of ship-generated waves in the historical centre of Venice —

Master Thesis

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Abstract

The objective of this work was to develop an application within a Geographic Information System (GIS) that permits an analysis of ship-generated waves in Venice for different time intervals. The variation in the traffic volume during one day results accordingly in a changing of the development of wake waves. With the information where and when strong wake waves are produced, new traffic rules, speed limitations or re-routing could be adopted. To realise this application, information about the ship-generated waves, formulas for their calculation, the 'moto ondoso' in Venice and the factor time in GIS had been studied.

When a ship moves through a sheltered area waves are produced that can lead to shore erosion. This phenomenon of wake waves is often discussed associated with high-speed vessels in inland waterways. In the historical centre of Venice a similar action occurs from the motorboats operating there, called 'moto ondoso'. This continuous wave motion forces damages on the foundations and results in expensive restoration work. Immense augmentation of energetic dispersion of mechanical power in the waters follows from the increasing number of motorboats in the last 50 years, which causes a constant degradation of the shores and the buildings along the channels. This problem is difficult to solve because without motorboats Venice would be paralysed but too much traffic has a destructive factor.
A formula to calculate the 'moto ondoso' for the special situation in Venice still does not exist. Due to the fact that there are many interacting factors that are nearly impossible to consider, a suitable formula has still not been found. The formula developed by Kriebel (2003), of the US Naval Academy, was used because he observed many important effects that were neglected by many others. But it is important to mention that this formula was developed for large displacement hulls and not for the boats in Venice, which has to be kept in mind.

In this application information constantly change in both space and time. These changes and their interactions need to be understood and considered for decision-making. Current GIS lack adequate capabilities of handling temporal information. Storing the temporal

information, a temporal GIS is able to answer questions such as where and when changes occur.
To give an overview of the possibilities of bringing time in GIS some spatio-temporal data models are presented.
The *Sequential Snapshot Model*, the most popular and simple approach, stores spatio-temporal information by time-stamping layers depicting the same phenomenon over the entire space, one for each time slice (Langran, 1992b). The *Base State with Amendments Model* stores one full version of a data set, and then stores separately the changes that occur (Langran, 1992b). The *Space-Time Cube Model*, a three-dimensional cube, represents one time and two space dimensions. The *Space-Time Composite Model*, similar to the Base State with Amendments Model, stores the amendments in the same database (Langran and Chrisman, 1988). The *Spatio-temporal Object Model* considers the world as a set of discrete objects, represented as two-dimensional spatial objects with the event-time as third dimension. The *Event-based Models* include three separate, linked models: location-, feature- and time-based. The *Three-Domain Model* represents dynamic features that change characteristics and locations continually (Yuan, 1994), based on semantic, time and space domains. Temporal changes in attributes (aspatial changes) can be distinguished in versioning at relation level, at record level and at attribute level.

The used data were taken from the project MANTA (Model for the Analysis of the Water Traffic), provided by the 'Consorzio Venezia Ricerche'. This project, realised by a multi discipline working group, developed a dynamic mathematical model for the representation of the water traffic in the historical centre of Venice. The results of the simulation model are analysed and dynamic visualised in GIS. The realisation of the temporal factor in GIS for the application MOON (MOto ONdoso) is based on the project MANTA and therefore constricted by using the already existing database.
For the realisation of the project MANTA different boat types with information about their hull characteristics were used as well as various information about the traffic network like the channel width, the speed limits etc. The data output, produced in ACCESS by the simulation model, is then used in ArcGIS to visualise dynamic the traffic for a given time interval, with the help of an extension implemented with ArcObjects.

For the realisation of the application MOON using data of the project MANTA, a macro in ACCESS was created, consisting of different queries. With the help of the queries the necessary records of the data output were chosen and then used to calculated the wave height with the formula of Kriebel (2003). In the queries of the final tables an additional criterion was used to make it possible to get just the data of a wanted time interval. A mask was also composed in which starting and ending time has to be entered and the macro can be run.

In GIS a button was implemented to start the macro from within GIS. With the simulation model the output of a whole day was compiled. In order to connect the traffic network with the new data output, first a database connection was realised in ArcCatalog and then the layer in GIS was joined with the wanted query in the database. Now it was possible to visualise in a fast and easy way any wanted time interval by using the button and entering the wanted starting and ending time in the mask. After the refresh of the map in GIS the actual time interval is shown.
The results of the wave calculation have to be valuated carefully. There are too many neglected factors which are important for a holistic observation. Therefore no detailed evaluation will be presented. But a qualitative evaluation shows that the results, regarding already known facts, seem to give a realistic description.

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Chapter 1

Introduction

Venice is unique in the world for many reasons, also in respect to its means of locomotion: nearly all transportation (persons, goods) go with the help of different kinds of motorboats. This motorboats generate waves, which make up the main part of the wash waves, the so-called 'moto ondoso'. Due to their consequent influence the foundations of the houses and channels in Venice get damaged.
The intensity of the 'moto ondoso' depends on many factors, wherefore its calculation represents a difficult undertaking.
Using data and a simulation model of the project MANTA, an application in GIS was realised with which the changing wave intensity during one day can be visualised.
One aim of this thesis is to give the case for the importance of incorporating time into GIS. To truly understand a phenomenon both location and time must be handled properly. This means that data should be administered using all components: attribute, space and time. Unfortunately most commercial GIS do not incorporate temporal functionality. Reason for this are serious conceptual barriers to handle time within the GIS data model. Consequently users are left on their own in how to use spatio-temporal data. This makes implementation difficult. To become a true decision support system GIS must become a spatio-temporal system.
The second chapter gives a review of the principles of ship-generated waves. It presents a formula for calculating the maximum wave height and introduces the theory of the residual resistance. Furthermore it gives an introduction of the impact of the wake waves in Venice. Chapter 3 reviews the issues with time in GIS, looking at some examples of how handling it within a GIS. A basic information of the project MANTA and a more detailed one of its data and model are covered by chapter 4. In the last chapter the preparation and realisation of the application MOON is explained and some results are presented.

Chapter 2

Ship-generated Waves

2.1 Physical Characteristics of Vessel Wash

This chapter will introduce to the basic concepts of ship-generated waves, their pattern and characteristics.

2.1.1 Wave Generation

When a ship moves forward in still water, the water around it gets disturbed. This becomes manifested in a flow back along the ship. To manoeuvre a ship in still water with a certain speed an external force has to be applied. The flow, which reaches the ship, has the same speed but in the opposite direction, generated by the means in which the hull moves.
At the bow the flow velocity rises relative to the ship and is deviated from a straight course by the slant hull form. This flow acceleration requires a pressure gradient active along the hull. There are different factors which influence the height of the pressure gradient and pressure change: the speed, the hull form and the shape of the channel cross-section. In a confined channel the flow acceleration and resulting pressure gradient are greater than in wide waters. (Sorensen, 1997)
The sharp pressure gradients at the bow and at the stern induce a rapid rise and fall in the water level. So the inertia causes the water surface to lag behind its equilibrium position and produces a surface oscillation. This again produces the pattern of free waves that propagate out from the ship (figure 2.1).
A wave generated by a vessel stands for the dispersion of energy provided by the motor which moves the water instead of the vessel.
The period and direction of waves are depending on the vessel speed and the water depth. The prediction of height of ship-generated wave heights is quite difficult because it is not

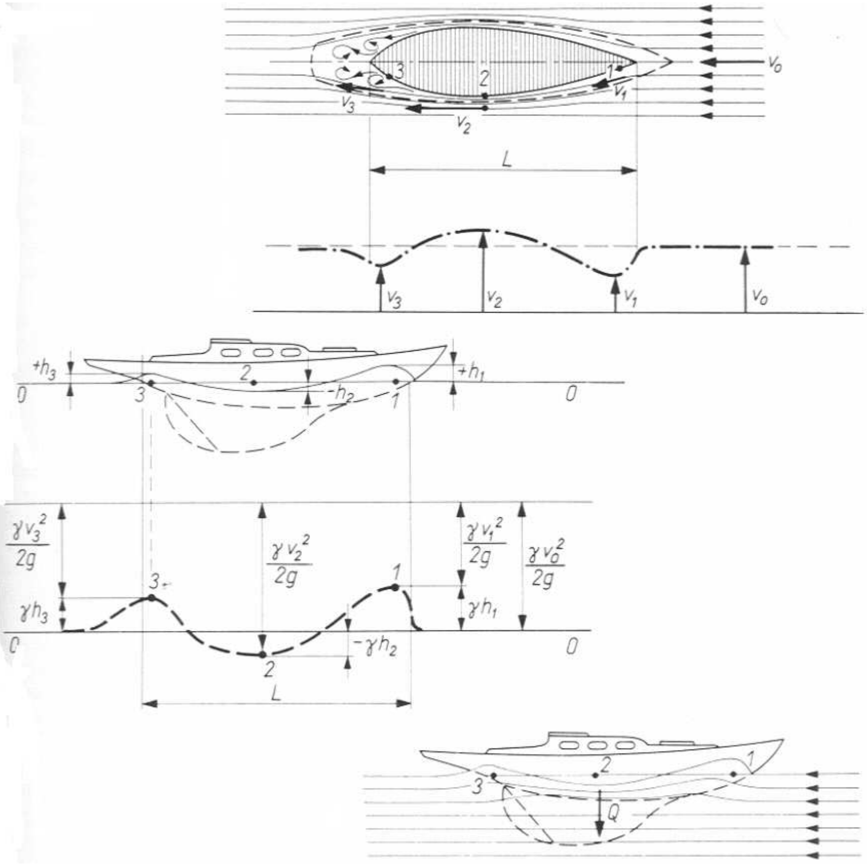


Figure 2.1: Process of wave generation by a vessel (Source: Consorzio Venezia Ricerche, 2002)

only depending on the speed and water-depth but also on the velocity of the flow past the hull, the hull form, the distance from the sailing line and the distance between the hull and the channel sides.
It should be taken into consideration that the wave height varies throughout the produced wave pattern (figure 2.2). Before undertaking a study, it has to be defined which wave height is being predicted. Currently the most commonly used numerical measure is the maximum wave height H_m. (Sorensen, 1997; Croad and Parnell, 2002)

As mentioned before, the pressure rises at the bow and stern and falls along the middle of the ship, responding in a raised water level at the bow and stern and a lowered water level along the midsection. According to this ship-generated wave heights, they may increase with increasing speed or increasingly confined channels. (Sorensen, 1997)
These contributions of pressure and speed affect the walls and shoals and provoke damages: the walls and the shoals dissipate the energy within themselves, or they transmit it to others. Since they are little coherent materials, because of their nature and age, it is quite easy to degrade them.

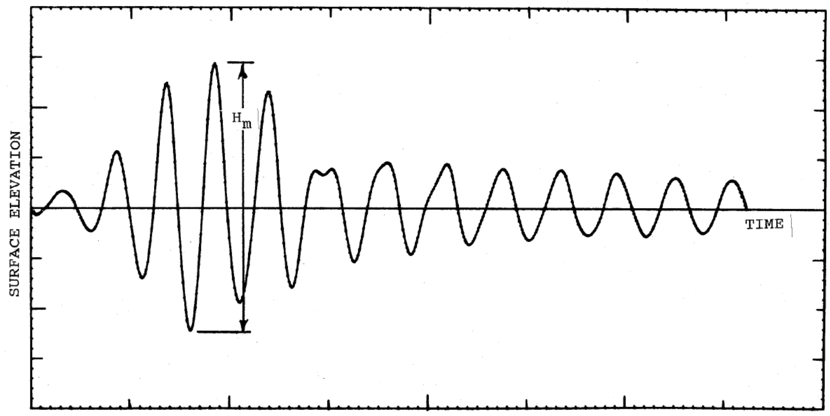


Figure 2.2: Typical vessel-generated wave record with the maximum wave height H_m denoted (Sorensen, 1997)

2.1.2 Characteristic in deep water

The pressure gradients, produced by the movement of a ship, generate a set of waves with a distinctive pattern. The first who studied the wash pattern in deep water was Lord Kelvin (1887). The pattern consist of two different types of waves: the transversal waves are the longer and faster waves with the same travel speed and direction as the vessel. The shorter and slower waves are known as diverging waves and travel obliquely out at an angle to the track of the ship (= sailing line). The transverse and divergent wave components meet to form cusps at a line with the angle of approx. 19 degree, called the cusp locus, shown in figure 2.3. Along this line the highest waves occur. (Sorensen, 1997; Whittaker and Elsäßer, 2000)

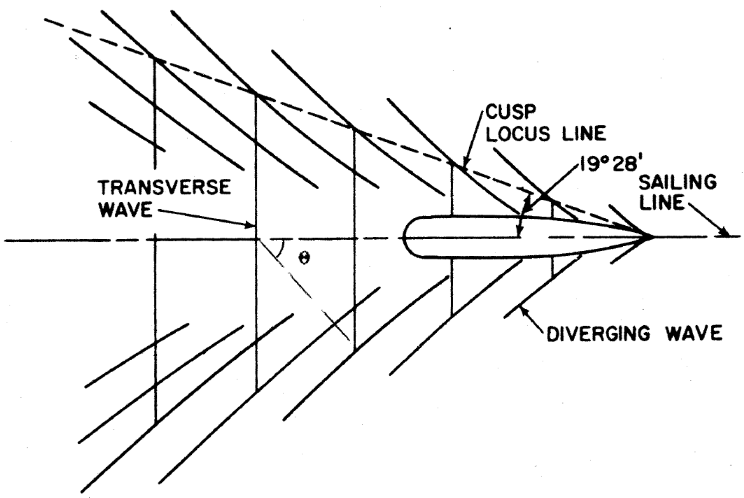


Figure 2.3: Deep water wave crest pattern of a moving vessel (Sorensen, 1997)

With increasing vessel speed the wave lengths increase and spreads out, whereas the

shape of the wave pattern stays the same.
The wave generation in deep water is characterised by a non-dimensional parameter, the length Froude number (F_L). It is a function of the vessel length and speed.

$$F_L = \frac{V_s}{\sqrt{g \cdot L_{wl}}}$$

where V_s is the speed of the boat (m/s), g is the acceleration due to gravity (m/s^2) and L_{wl} is the ship length at waterline (m).

2.1.3 Characteristic in shallow water

Havelock (1908) described the wash by vessels for finite-depth water and classified the wash in terms of the depth Froude number. The depth Froude number is another non-dimensional number and indicates the characteristic of the wave pattern around vessels moving in shallow water. This is defined as the ratio of ship speed to the maximum velocity a wave can travel in a given water depth, given by the formula:

$$F_d = \frac{V_s}{\sqrt{g \cdot d}}$$

where V_s is the speed of the boat (m/s), g is the acceleration due to gravity (m/s^2) and d is the still water depth (m).

Sub-critical Depth Froude Number In the case that a wave travel in water with a depth of less than approximately half the length of the wave, the wave starts to interact with the bottom and this fact affects the wave characteristics (figure 2.5). For the longer transverse waves this occurs when the depth Froude number reaches a value of 0,56. The shorter diverging waves start to interact a bit later than the transverse waves, at a greater Froude number. This can be the consequence of a reduction of the water depth or an increased speed or both together. Between the Froude number of 0.56 and 1 the longer waves become continuous less dispersive and their energy is largely conserved in individual waves. In general the ship-generated waves begin to respond to the water depth effects when the Froude number is greater than 0,7. (Sorensen, 1997; Maritime and Coastguard Agency, 2001)

At Froude numbers from 0,7 to 1 the wave heights continue to rise, whereas the transversal waves increase faster than the diverging waves. Hence, the transverse waves become more dominant as the Froude number reaches unity, and the cusp locus angle increases from the deep water value of 19 degree to 90 degree.

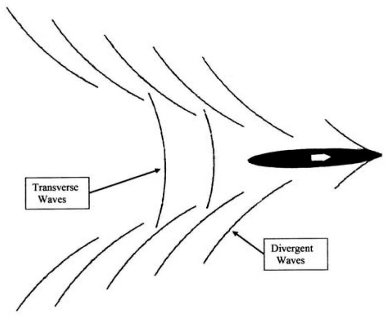


Figure 2.4: Sub-critical wave pattern (Libby, 2003)

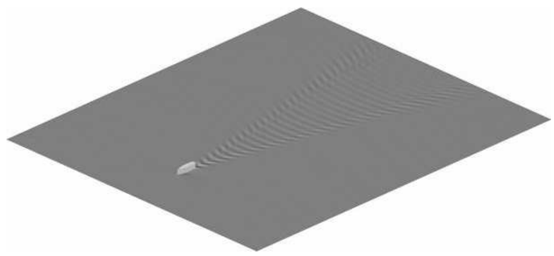


Figure 2.5: Representative wave systems for $F_d = 0,7$ in shallow water (Jiang et al., 2002)

Critical Depth Froude Number When the maximum speed and energy a wave can contain in a given water depth, equals the speed of the ship, it is known as the critical depth Froude number F_d = 1,0. The celerity of the ship and the velocity of the waves are equal to d. The cusp locus line angle is 90 degree and the transverse and diverging waves conjoin with their crests nearly perpendicular to the track of the ship - the transverse waves disappear and the diverging waves remain (figure 2.7). All of the wave energy is focused in a large leading wave, at the expense of the following waves, near the bow perpendicular to the sailing line. (Sorensen, 1997)
Vessels should not operate over a longer period at critical speed, because very high energy levels are transmitted continuously to the waves, and manoeuvre should be avoided. Normally a ship creates more wash during manoeuvres in comparison to a straight course. (Libby, 2003)

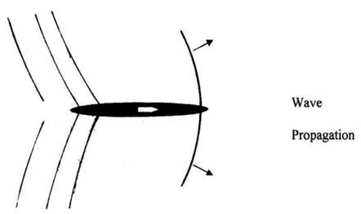


Figure 2.6: Critical speed wave pattern (Libby, 2003)

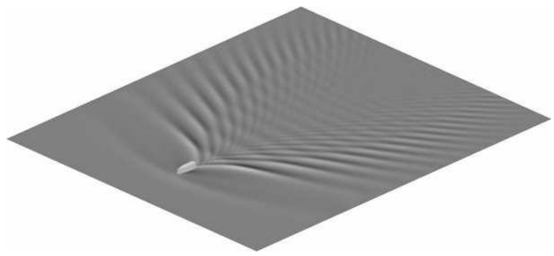


Figure 2.7: Representative wave systems for $F_d = 1,0$ in shallow water (Jiang et al., 2002)

Super-Critical Depth Froude Number The velocity of a wave cannot exceed the critical speed. In the super-critical region, for vessel speeds with $F > 1$, the wash pattern changes its appearance (figure 2.9). The critical wave and the transverse waves, existing before the ship entered the super-critical region, cannot keep up, so that the resulting wave system consists of a series of straight diverging waves: a straight leading wave and a subsequent concave wave crest close to the ship.

At Froude numbers greater than unity, the wave heights are less than at critical Froude number ($F = 1$) and decrease with increasing vessel speed. (Sorensen, 1997)

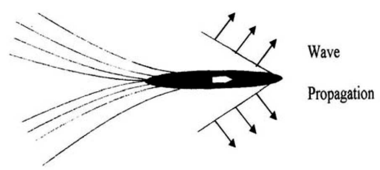


Figure 2.8: Super critical wave pattern (Libby, 2003)

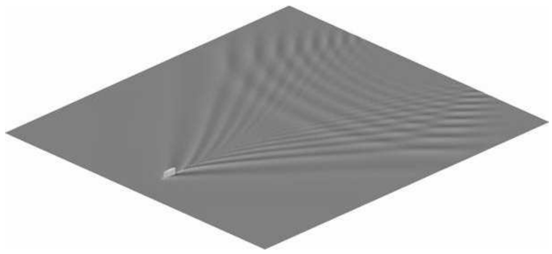


Figure 2.9: Representative wave systems for $F_d = 1,5$ in shallow water (Jiang et al., 2002)

Transcritical range At Froude numbers within the transcritical range of approx. 0,9-1,1 the highest waves occur. During acceleration and deceleration it cannot be avoided passing this speed range. Therefore it is very important to decide where the acceleration and deceleration take place. It is of great importance to perform them as fast as possible because the height of the wave depends also strongly on the time spent within this range. (Single, 2001)

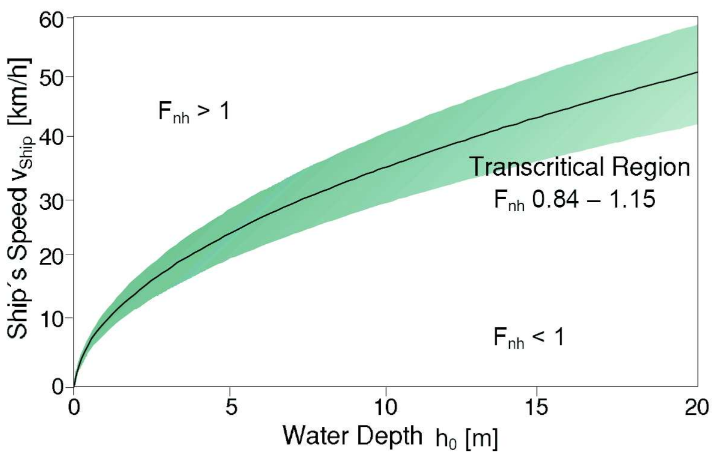


Figure 2.10: Subcritical, transcritical and supercritical speed range (Huesig et al., 1999)

Influencing factors Reference has already been made to the critical speed at a depth Froude number of unity, where the ship travel with the same speed like the wave through the water. Typically this results in a peak of the wave height generated by the ship hull. When a ship is travelling at constant speed in decreasing water depths the Froude number increases like shown in figure 2.11.

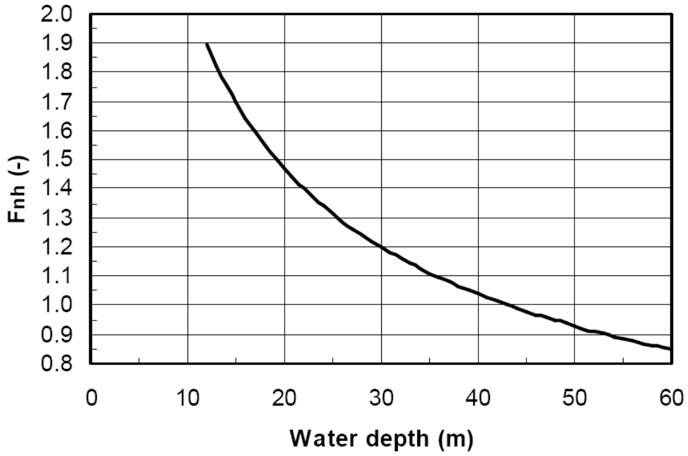


Figure 2.11: Relation between depth Froude number and water depth at a speed of 40knots (Single, 2001)

The typical relation between the maximum wave height and depth Froude number is shown in the following figure on the example of two vessel types.

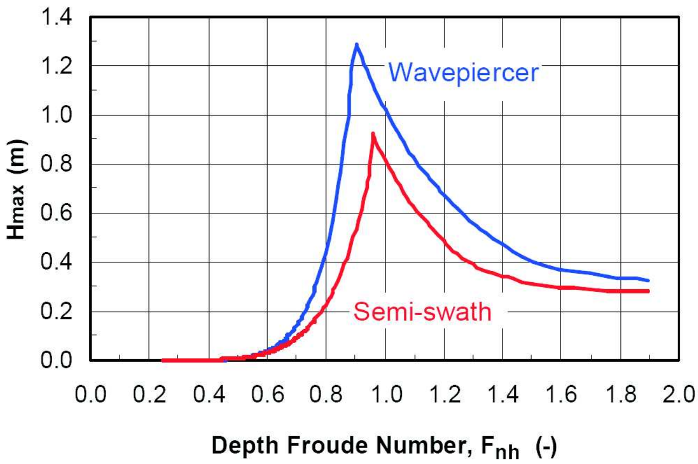


Figure 2.12: Typical relations between depth Froude number and maximum wave height, 700m from navigation track (Single, 2001)

Also the length Froude number affects the wave properties. When the length Froude number is in the range of 0,4-0,6 the maximum reinforcement between stern and bow exists. If a vessel would operate below the critical speed an increasing hull length would reduce the wave height: 'hull stretching' is an effective means to reduce wave impacts. (Croad and Parnell, 2002)

The reason why a complete study of wake wash is very complex, is the fact that there are many factors which are interacting. As Macfarlane and Renilson (1999) specified these are the following points which have to be noted.

– Vessel related: speed, direction, hull form, draft, loading, trim

– Environment related: water depth, tide level, tidal stream direction and velocity, coastal morphology, wind wave characteristics, subsurface flows

– Above all: distance from sailing line, wake interactions, location of measurement sites

2.2 Predictive Model for wave heights

The task was to find a predictive model to calculate the ship-generated waves in the historical centre of Venice. The model of Kriebel (2003) was chosen, which will be described more in detail in the following section. A general good overview and discussion of other nine predictive models are given by Sorensen (1997).
It is quiet difficult to choose a suitable model from the existing ones for the special case of Venice. The predictive models found in literature were all conceived for large vessels moving in deep water. The objective of Kriebel (2003) was to develop an empirical equation to predict the maximum ship-generated wave heights for large displacement hulls. It has to be assumed that in general a model is developed for a certain type of vessel and perhaps does not deliver quantitative correct results when applied to other ship types. Also the listed literature of Kriebel (2003) discusses ship-generated waves only for large vessels.
As of yet, no equation for boats, with dimensions, as existing in Venice, could be found, nor a predictive model for the Venice's unusual situation. Kriebel (2003) developed the model by including and improving three existing predictive equations. He considered variations in the hull geometry, wave height decay with the distance from the sailing line, ship speed and the water depth. The next sections will go into detail about the development of the formula.

First of all the wave height, distance from sailing line, water depth and velocity got normalised: the wave height by the velocity head ($\frac{g \cdot H}{V^2}$), the distance from sailing line (y) by the ship length (L) to $\frac{y}{L}$, the water depth got normalised as depth-to-draft ratio ($\frac{d}{T}$) and the speed as Froude number.

Depth to draft ratio As already known from earlier executions the wave height in shallow water is strongly affected by the water depth. This can be expressed with the depth to draft ratio $\frac{d}{T}$. In a range from $\frac{d}{T} > 3$ to 5 no more strong interaction with the sea floor happen.

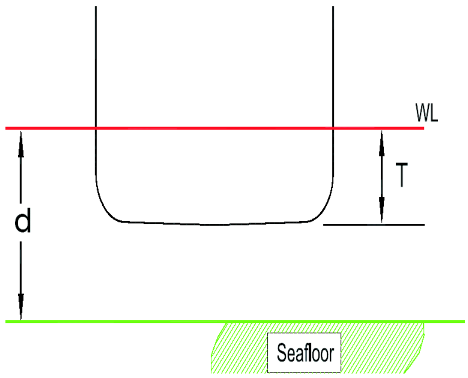


Figure 2.13: Depth to draft ratio (Kriebel, 2003)

Variation of the wave height H with the distance to sailing line By studying the theory of Havelock (1908) for deep water and empirical evidence in writings, Kriebel (2003) found the best fit with:
$\frac{g \cdot H}{V^2} = C \cdot \left(\frac{y}{L}\right)^{-\frac{1}{3}}$
where:
y = distance from sailing line
C varies with ship hull form, $\frac{T}{d}$ and F_L or F_d

Froude Number The speed of the vessel can be normalised as depth-based Froude number $F_d = \frac{V_s}{\sqrt{g \cdot d}}$ or length-based Froude number $F_L = \frac{V_s}{\sqrt{g \cdot L}}$. Here occur the conflict that the depth-based Froude number works just in shallow water, not in deep water and the length-based Froude number the opposite way round. Kriebel (2003) developed a modified Froude number that works across all water depths:
$F_* = F_L \exp\left(\alpha \cdot \frac{T}{d}\right)$
where α is dependent on the hull form.

Variation of α with hull form The empirical coefficient α depend mainly on the Block Coefficient $C_B = \frac{D}{B \cdot T \cdot L}$ (figure 2.14). For streamlined ships α reaches unity or more, for blunt hulls α ranges from 0,2 to 0,4:
$\alpha = 2,35\,(1 - C_B)$

Relationship between $\frac{g \cdot H}{V^2}$ and F_* For the relationship an adapted quadratic expression is used. There is no simple mathematical function which ideally describes all data for all types of hulls. In general $\frac{g \cdot H}{V^2}$ increases with F_*.
$\frac{g \cdot H}{V^2} = \beta\,(F_* - 0,1)^2$
where β varies with the hull form, more precisely with the entrance length L_e.

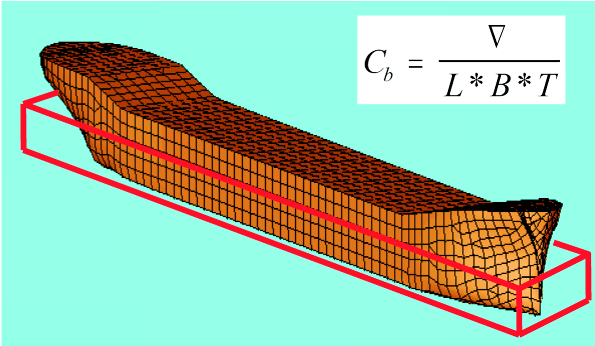


Figure 2.14: Block coefficient (Kriebel, 2003)

Variation of β with hull form Kriebel (2003) found the best correlation with the ratio $\frac{L}{L_e}$. Streamlined hulls have a β of 1-2 against what blunt hulls reaches up to 9.
$\beta = 1 + 8\tanh^3\left(0,45\left(\frac{L}{L_e} - 2\right)\right)$

Proposed Formula of Kriebel (2003)

$$\frac{g \cdot H}{V^2} = \beta\left(F_* - 0,1\right)^2 \cdot \left(\frac{y}{L}\right)^{-\frac{1}{3}}$$

where:

$$F_* = F_L \exp\left(\alpha \cdot \frac{T}{d}\right)$$

$$F_L = \frac{V}{\sqrt{g \cdot L}}$$

$$\alpha = 2,35\left(1 - C_B\right)$$

$$\beta = 1 + 8\tanh^3\left(0,45\left(\frac{L}{L_e} - 2\right)\right)$$

$$C_B = \frac{D}{B \cdot T \cdot L}$$

2.3 Residual Resistance

A research, some years ago, conducted by the "Technical Commission for the Study of the Wake Wash" of the local authority of Venice, yield to the definition of new speed limits for the historical centre of Venice and a limit curve of the residual resistance (R_R), which the Venetian boats should have fulfilled. The proposal of the limitation according to the residual resistance had never been implemented. Zotti (2002) explains why the use of the R_R had been suggested and considers this criterion for technical validity.

The following will give a simple explanation of the residual resistance.
A body that moves on the undisturbed surface of the water produces a wave system. This system is generated by the field of pressure around the body and the energy possessed by the waves is given to them by the body itself. This transfer of energy from the body to the surrounding system generates a directional force opposite to that of the movement, which is the residual resistance.
In a nutshell: the residual resistance (R_R) presents all resistances affecting a body's motion through the water excepting friction and among other things its dependence on the hull form.

For the situation of the lagoon of Venice there have been made numerous tests to correlate the waves heights with the engine-power, the speed and the hull form. There are many circumstances beyond the control of experimental tests, like the weight, the propulsion, the water depth and the distance from the channel sides etc. These factors influence every attempt of correlation, creating indeterminable uncertainties. (Consorzio Venezia Ricerche, 2002)
But there are some coherences like the relations regarding the trains of wave and the ship proportions, the length in particular. It is for sure that a long and straight hull form produces smaller waves than a short and beamy one. Also a streamlined bow is better than wide and rounded one. If the weight of a boat got reduced, the water displacement decreases also and thus the size of the produced waves. A light and streamlined boat makes less waves than a wide and heavy one, based on the fact that they have the same length.

As mentioned in Chapter 2.1.2 the wave height depends also on the velocity of the vessel. The speed-length ratio ($\frac{V}{\sqrt{L}}$ velocity divided by the square root of the length) permits the comparison of the performance of hulls with different lengths.
From this relationship the relative speed of the hull is given. Since this relationship depends on the units that are used in order to express the velocity V and the ship length L, it is preferred to use the non-dimensional length Froude number F_L.
The critical value of F_L is 0,4 when the wave length generated by a boat at a certain speed equals the length of the ship. Thus at a length Froude number of $F_L < 0,4$ the length of the waves are shorter than the length of the vessel, and at $F_L > 0,4$ they are longer.

The Consorzio Venezia Ricerche (2002) worked out a proposal for the evaluation of residual resistance limits for the lagoon of Venice. It describes a proposed norm to validate the residual resistance of different hulls used in the lagoon of Venice, and the definition of a limitation in function of the typology and the dimensions of these hulls.

2.3.1 Conventional Residual Resistance of the Hull

In order to elaborate an applicable criterion, without running tests in tanks or using calculations difficult to apply, it has been utilised and modified the formula of Taylor. It allows to estimate, with an acceptable error, the residual resistance in kilogramme of a hull. The ship length (length at waterline is approx. 90%) and the displacement are needed for the calculation.
The original formula of Taylor is:

$$R_0 = \frac{K \cdot V^4 \cdot D^{\frac{2}{3}}}{L_{wl}}$$

where:
K varies from 0,048 to 0,070, adaptive for $\frac{V}{\sqrt{L}} < 2$
V the velocity of the vessel in knots
D is the displacement in ton
L_{wl} ship length at waterline in meters

In order to lead all back to the customary units used in the lagoon environment (ship length, displacement in tons, speed in km/h) and above all to adapt the formula to the design of the existing hulls, it has been rewritten to:

$$R_0 = \frac{K_n \cdot V^4 \cdot D^{\frac{2}{3}}}{100 \cdot L}$$

where:
V the velocity of the vessel in km/h
D is the displacement in ton
L_s ship length in meter

With K_n changing with the category, depending on the hull form:

The curve of the residual resistance limits, issued by the "Technical Commission for the Study of the Moto Ondoso" of the local authority of Venice, was calculated using the equation (kg, km/h):

$$R_R = -39,2778 + 16,9561 \cdot V - 1,78759 \cdot V^2 + 0,0895655 \cdot V^3 + 0,00134761 \cdot V^4$$

By comparing the curves of the different boat types with the curve defined by the "Technical Commission for the Study of the Wake Wash" it can be simply verified, within an approximation margin, at which speed the thresholds are respected.

Category	hull form	type	boat length (m)	relative speed	displacement (t)
$K_1 = 0,52$	round hull	public transport	12-25	$\frac{V}{\sqrt{L}} < 4,2$	5-55
$K_2 = 1,19$	streamlined, half-round	taxi and similar	7,5-12	$4,2 < \frac{V}{\sqrt{L}} < 6,5$	3-5
$K_3 = 0,83$	streamlined, half-round	lancione and similar	12-25	$\frac{V}{\sqrt{L}} < 4,2$	5-55
$K_4 = 0,85$		boats for transport		$\frac{V}{\sqrt{L}} < 4,2$	5-35
$K_5 = 0,80$	streamlined, half-round		2,5-7,5	$\frac{V}{\sqrt{L}} < 7,3$	0,3-4

Table 2.1: Categories for the calculation of the residual resistance limits (Consorzio Venezia Ricerche, 2002)

2.3.2 Specific Residual Resistance and Relative Limit

The value of the specific residual resistance of a hull refers to a ton of displacement at full cargo, at considered speed. The maximum speed must be limited so that it does not exceed the limit of residual resistance per ton of displacement, defined as follows.

Category 1:	$R_1 = 42,8 - 0,56 \cdot displacement(t)$
Category 2:	$R_2 = 145 - 6,25 \cdot displacement(t)$
Category 3:	$R_3 = 121 - 3,15 \cdot displacement(t)$
Category 4:	$R_4 = 10,7 - 0,13 \cdot displacement(t)$
Category 5:	$R_5 = 350 - 80 \cdot displacement(t)$

Table 2.2: Definition of the residual resistance limits (Consorzio Venezia Ricerche, 2002)

To get the limit of the residual resistance from the result of R_n this has to be multiplicated by the displacement.
$R_R = R_n \cdot D$

2.4 Wave Wash in Venice

In the lagoon of Venice there are two causes for the wave wash: the wind and motorised boats.
The behaviour of the 'moto ondoso' generated by the wind varies with the direction and force of the wind and other factors, like the characteristics and depth of the ground. The winds Sirocco and Bora causes sometimes strong seas storms which can have serious consequences for shorelines and ambience.
Waves produced by the wind can also be created inside the lagoon of Venice but for the

insufficient depth and the small distance the wind can act on the free surface of the water, they can reach only a modest size. Sometimes they have the ability to damage the shoals and the structures of the fishery.

The waves inside the lagoon, caused by the wind and above all by the motorboats, are mainly small but they can provoke over a long period, negative effects on the natural and delicate structures.
Considering just the channels of the historical centre of Venice, measurements which had been carried out for the 'Canal Grande' confirm that waves from wind do practically not exist, but do so with waves due to motorised water traffic. In consideration of the progressive increase of the traffic, it is from these waves that the city has to be defended, because its shores, foundations and monuments have not been conceived neither constructed in order to support this type of solicitations. (Brighenti et al., 2003)

In the historical centre of Venice the 'moto ondoso' is created for the most part from passing boats endowed of more and more powerful motors and of the shape of their keels. The incessant activation of the waves produced by private motorboats, boats for public and goods transport causes a constant degradation of the shores and the buildings along the channels. The impact of the waves affects material already damaged and weakened by the humidity and saltiness. By and by this effect arises in small fissures that gradually increase. The air inside these fissures gets compressed by the waves acting on them and transmits to the structures a reinforced effect. Even if it does not provoke problems of stability at least it will lead to complex and expensive maintenance work. (Brighenti et al., 2003)

In the last ten centuries the transportation in Venice has always been a preoccupation of the government with a constantly see-saw between the existence of the nature conservation and the anthropogenic necessity between socio-economic development and isolation.
It is the fact that the 'moto ondoso' and the lagoon traffic never had been constituted as a problem in the modern age, at least until the first half of the 20th century. In previous centuries, the greatest hydraulic problems of the lagoon were the regiments of the affluent waters and the city had 30.000 boats equipped with oars or sails, for transportation in Venice. This situation changed in the post-war period when the number of the boats in the lagoon increased. (Consorzio Venezia Ricerche, 2002)

Particularly it has to be mentioned the immense augmentation of energetic dispersion of mechanical power in the waters of the lagoon, resulting from a deeply technically changed fleet - a dispersion grown thousands of times in a few years. (Consorzio Venezia Ricerche, 2002)

Today the problem of ship-generated waves in the historical centre of Venice is trying to

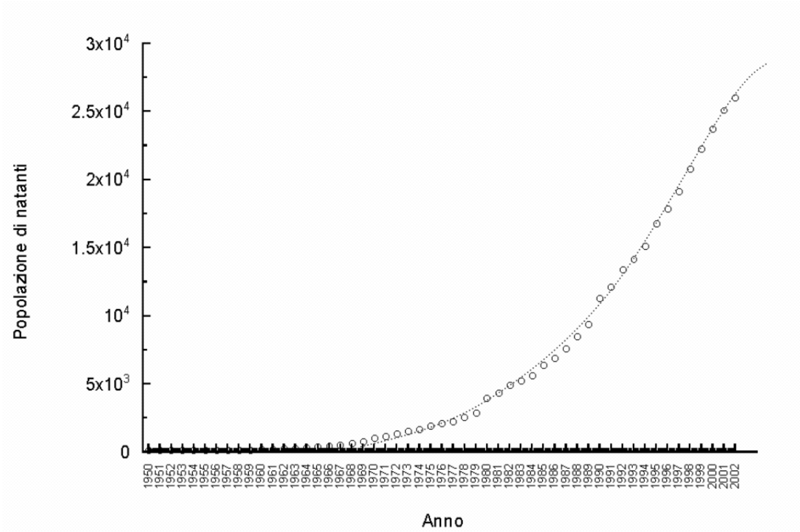


Figure 2.15: Increase of the boats in Venice from 1950 to 2000 (Consorzio Venezia Ricerche, 2002)

be confronted with speed limitation and traffic control.

The problem of the 'moto ondoso' has to be countered by a combination of measurements, made to control the phenomenon and to keep it within a tolerable level for Venice. In addition to these measures there is, first of all, the need of basic information, in particular for the actors of navigation. (Brighenti et al., 2003)

2.5 Environmental Impact

The following outline about the environmental impacts and their genesis are based on the report of Brighenti et al. (2003).

The main part of energy that a moving boat transmits to the water and then discharges on the sides of the channels, is connected to the generated wave trains and can be measured through the parameter residual resistance. The energy supplied to the water from a motorboat in narrow waters comprises also the perturbations connected to the motion of the propeller.
The rendering of the energetic transmission of the propeller is, relative to the motion, low and normally inferior 55-60%. It generates jets of water, vortices and turbulences, pressure variations, with formation of currents. The energy, developed from the motorboat, transmitted to the water, produces much greater damages on the sides of the channels or the ground, when there is not enough space in which the wave can dissipate its energy in inner friction to the fluid.

In addition to the energy transmitted by the maintenance of a uniform motion, it has to be added the energy that is produced by acceleration, deceleration and manoeuvres.

Before passing to the explanation of the degradation mechanisms a callback to the structure of the system of the channel-sides and the foundations in the historical centre of Venice is upper importance.
The city of Venice was founded in the ambience of a lagoon, originated by inflow of mud and water by rivers. Because of the particular nature of the ground the constructors realised the foundations along the water course made with the techniques of the time and with the locally available materials.
The foundations were placed on boles of holm oak, placed in order to counteract the land erosion, set up in the parts of the natural river bed where the more consisting clay layers have been. The clay layers were found in a depth of two meters under sea level.
In the underground, integrated in the system of the foundations, a network of small sewers were realised to permit the drainage of the reflux in the channels. They have a fundamental role for the hygienic maintenance of the city.
Over the boles a support of larch or oak is situated on which the wall foundations for the channels and buildings stand.
To make this fragile and complex system work, it has to be integral, efficient and regularly maintained. The channels must have the natural water level and the mud must not obstruct the outlet of the ducts.

There are many factors that can affect the integrity of this system, like the chemical and physical attack of the ambience, the collision of manoeuvring boats and the whirling jets of their propellers, and for sure the channels and the foundations of Venice have not been conceived to support the wake wash of the motorised traffic.

The sides of the channels in Venice have in general vertical walls, which reflect the waves totally. When the propagation direction is perpendicular to the walls, a wave with the double size of the initial one comes out. If instead the front line of the wave arrive oblique, the system of the reflected waves proceeds symmetrically to the initial one. The waves beating on the wall generate pressure. If these forces act on a structure constructed and maintained, it can remain entire.
This emphasises the erosive phenomenon of the interstice and the irreversible wash out process of the fine fraction of the material behind the wall. The phenomenon culminates in the collapse of the foundation, of the masonry or of the trench.

With the presence of external erosions starting to take place, including the removal of the malta in the interstices between stones or bricks, little fissures emerge so that the water comes into contact with the incoherent material of the foundation (sand or clay). The

Figure 2.16: Impact on the foundations by 'moto ondoso' (Brighenti et al., 2003, Source: INSULA SpA)

erosion can also be provoked from inside of one duct of drainage reflux, forced by the pressure produced from wake waves.

The degradation take also place in the channels of the open lagoon. Many fairways must be often dredged to keep them navigable. This is closely connected with the generated waves of the boats, navigating through these channels. The waves disperse the bottom sediment, which then deposit, dragged from the produced currents, in the deeper zones of the channel.
This phenomenon is particularly relevant for the great channels, sailed by great ships, which need to be frequently dredged. But it is also meaningful for the channels of medium largeness.

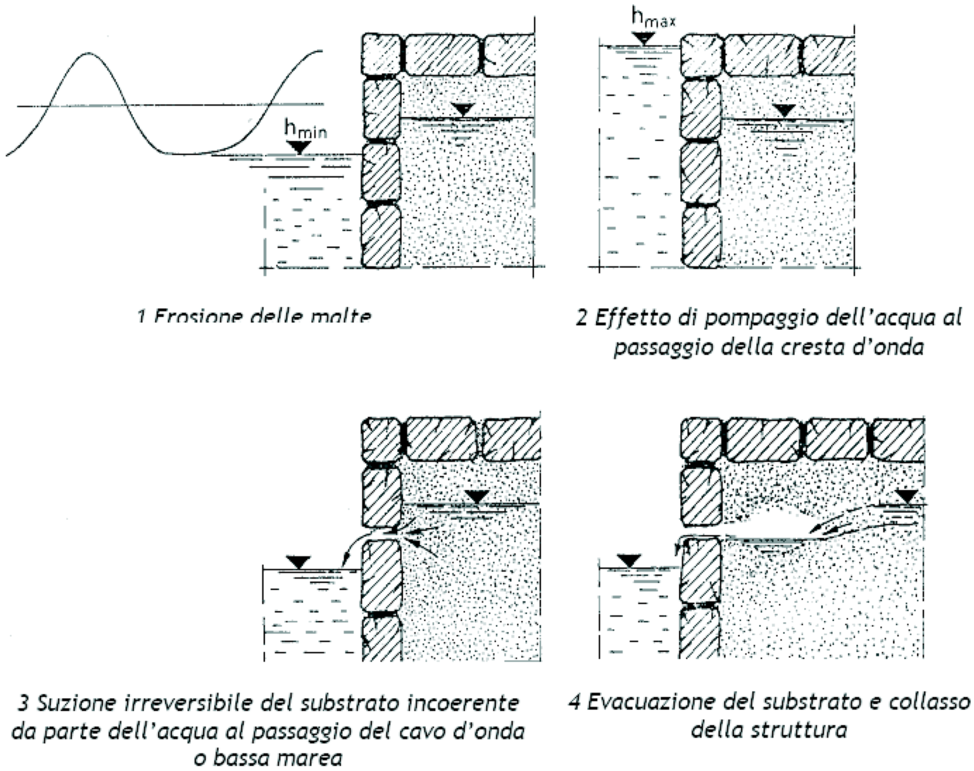


Figure 2.17: Degradation on the sides of the channels caused by the boat-generated waves (Brighenti et al., 2003)

Chapter 3

Spatio-temporal GIS

Currently, commercial GIS software systems lack the capacity of representing temporal and real 3-D information, and have difficulty in spatio-temporal dynamic simulation (Langran, 1992b; Peuquet and Duan, 1995).

The first temporal GIS attempts were developed by Langran and Chrisman (1988) in the late 1970's. Since Langran's work (Langran, 1992b), temporal GIS has been popularly studied and several spatio-temporal models were proposed.

In the field of temporal GIS research there are two quests. One is concerned to practical applications including time in existing GIS (Halls and Miller, 1996; Langran, 1992b; Langran and Chrisman, 1988; Zhong and Dingqiang, 1996). These efforts affirm the limitations of the databases, searching to develop methods to work with temporal data. Prototype temporal GIS have been developed often with the focus on a specific application. (Halls and Miller, 1996; Zhong and Dingqiang, 1996)

The second attempt is focused on the theoretical goal to develop a temporal GIS aside existing GIS systems. (Langran, 1992b; Halls and Miller, 1996; Yuan, 1996; Zhong and Dingqiang, 1996)

These spatio-temporal data models extended conventional GIS vector and raster models to have the capability of representing spatial objects and modelling spatio-temporal relations in GIS environment.

Temporal property of geographical entities were conventionally seen as an attribute of planar objects, which can not represent the complete implications of temporal information, just specify a temporal position for spatial and attribute domains.

3.1 Time in GIS

Types of time representation

Time can be modelled as: linear time (extending from the past to the present, and into the future), cyclical time (repeating cycles such as seasons or days of a week), branching time (possible scenarios from a certain point in time onwards) and multi-dimensional time (seldom dealt in a GIS). (Freelan, 2003; Kainz, 2004)

Time can be represented as absolute or relative time. Absolute time is a point in time where a event occur, e.g. '23 May 2003 at 5:00 p.m.'. As the name implies relative time is specified relative to points in time e.g. last week, yesterday, a day later.

And time can be discrete or continuous. Discrete time means that time was measured at certain time points or intervals and the variation between them is discontinuous. To describe for example processes continuous time is required. Between measured time points the values can be interpolated on a continuous axis.

Domains of Geographic Information

Geographic Information has three domains: the spatial domain, temporal domain and attribute domain. In general each spatio-temporal model is based on this three types of data. All together represent the values of the attributes of an object which has a certain position (spatial data) at a certain time (temporal data). (Peuquet, 1994)
This spatio-temporal structure is shown in figure 3.1.

When the spatial domain is kept fixed it is possible to analyse the attribute changes over time for a given location, e.g. to know how a land cover changed for a given location over time, providing that its boundaries did not change. Whereas keeping the attribute domain fixed, spatial changes over time for a given thematic attribute can be examined, e.g. which locations were covered by forest over a given period.
When both spatial and attribute domain are variable it can be considered how an object changed over time, which leads to an object motion e.g. weather forecasting. In spatio-temporal data models changes of spatial and thematic attributes over time are observed. (Kainz, 2004)

Semantic spatio-temporal data models

Langran (1992a) proposes three types of spatio-temporal data in GIS used to describe

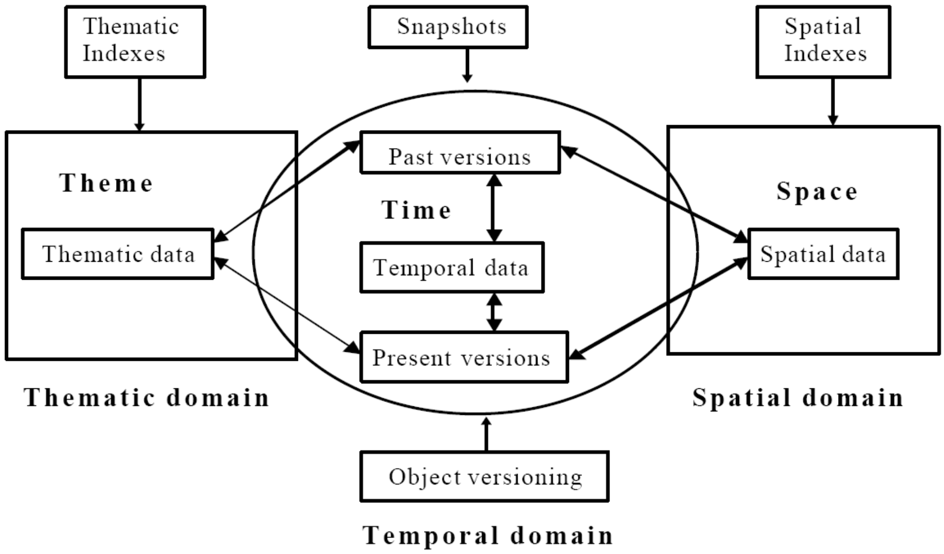


Figure 3.1: Spatio-temporal structure and framework (Peuquet, 1994)

time dependent objects. They give information about the state of an entity at a given time and the changes that occur.

- State: the state represents the entity at a certain time. It has a duration and is represented by time intervals.
- Event: an event, related with the evolution of an entity, causes changes of the state of an object. It is momentanly, represented as a time point. A further distinction can be made between events and episodes: if a change occur over a longer period, it is called an episode and represents a time interval.
- Evidence: the evidence can be seen as tracks of the evolution of an entity and can be used to trace the evolution of an entity.

Spatio-temporal Data

Data can be both static and dynamic. These two types of information need to be modelled under a temporal GIS. Many phenomena are described as a static-map displaying information of the real world. The static-maps are produced using the GIS as a powerful tool to create complex spatial model. However, geographic phenomena are normally dynamic in nature. (Nadi and Delavar, 2003)
Static information can be e.g. surface elevations, soil types, physical structures thus represents data, which changes infrequently. Dynamic information include information that

change over time such as weather, traffic conditions etc.
Spatial information can have different dynamic aspects; over time features can have: (Nadi and Delavar, 2003)

- geometrical changes (e.g. expansion of a town),
- positional changes (e.g. movement of a boat),
- attribute changes (e.g. traffic volume).

Dynamic data can also be distinguish in: (Nadi and Delavar, 2003)

- Real time data: the term real time means that data are stored in the GIS database as soon as or soon after the information is generated (within minutes). A real time GIS has the ability to manage, visualise and analyse the information as soon as the data was putted in.
- Near real time: near-real time data means that it is reported within some hours of being measured. A near real time GIS signify that the data, before it can be used, e.g. must run through complex data analysis and processes.

Dimensionality of time

An event can have different time representations, saved for example as an attribute. The following two time dimensions are important to construct a temporal database. (Zhao, 1997; Freelan, 2003)

- World time/valid time: represents the time when an event occurred (i.e. the time of creation or destruction of a feature or an event). This time is the more interesting for GIS users because it is the temporal information that supports spatio-temporal analysis. To be able to make a historical recall of past events or features the temporal GIS must maintain world time.
- Database time/transaction time: represents the time at which a feature or event was stored or updated into the database (typically sometime after the time of actual occurrence). This time is important for the maintain of the database history and the usage of the data for analysis and decision making.

The mentioned time dimensions get used in a temporal GIS database to give temporality by time-stamping every datum. (Zhao, 1997)

Different Forms of Temporal Databases

Both valid time and database time allow the distinction of different forms of temporal databases. (Shaw, 2000)
In conventional databases the stored data are considered to be valid at time present now, they do not trace past or future database states.
A first step toward a temporal database thus is to time-stamp the data. This allows the distinction of different database states. In the relational data model tuples are time-stamped, whereas in object-oriented data models objects and attribute values may be time-stamped.
Snodgrass (1992) classified temporal databases according to the terms of time, which they support:

- Snapshot database: commercial DBMS store only a single state of the real world, usually the most recent state.
- Historical database: stores data with reference to valid time and so describes the history of objects from today's view.
- Rollback database: stores data referring to database time and so describes the change of history of the database referring to database time.
- Bi-temporal database: stores data with respect to both valid time and database time. Thus both subsequent changes and future changes are completely saved.

If an temporal GIS includes both world and database time, queries about the lifespan of an object/event and the duration of the database's record of the object/event can be made. In other words, it is not only possible to reconstruct past states but also different versions of different states. (Freelan, 2003)

The granularity gives information about the precision of a time value used in a database (e.g. year, day, second, etc.). Depending on the application different granularity is necessary. The granularity can be a day for cadastral applications, but for geology mapping a time granularity in the order of thousands of year is more probable. (Kainz, 2004)

3.2 Spatio-temporal Data Models

In the following the major characteristics of some popular spatio-temporal models will be described.

3.2.1 Spatial Change

Langran and Chrisman (1988) proposed relatively achievable methods for including temporal data within a current two-dimensional GIS: the *Snapshot Model*, the *Time Cube Model*, the *Base State with Amendments Model* and the *Space-Time Composite Model* (Halls and Miller, 1996; Yuan, 1996). In the following section the basics of these models will be explained.
Supplementary some other models will be introduced: the *Spatio-temporal Object Model* (Worboys, 1992), *Event-based Methods* (Peuquet and Duan, 1995; Peuquet, 1994) and the *Three Domain Model* (Yuan, 1996).

Sequential Snapshot Model

The most popular and simple approach of implementing time in GIS is the *Snapshot Model*. The temporal information is incorporated into a snapshot spatial data model by time-stamping the layers. A time-slice saves a phenomenon at a given time saving all spatial and attribute data. It simply creates an entirely new copy of the database. Thus the time-stamp of the *Snapshot Model* is not applied to the individual features but to the entire dataset.
This approach shows only states of geographic data at different times but not the events that change from one state to another. The intervals of the layers are not necessary equal. Every layer is disjoint from every other layer unable to describe temporal relations between them.
The *Snapshot Model* is a fast and easy way to analyse states but has many shortcomings.

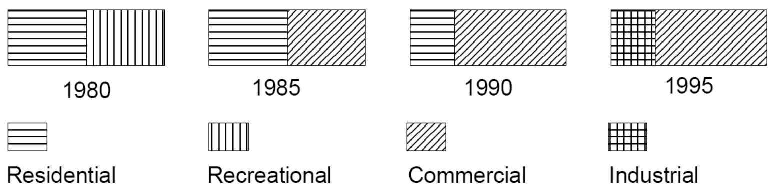


Figure 3.2: Example of a Snapshot approach (Raza, 2001)

Changes of spatial and attribute data cannot be examined because of its lack of temporal connections between the features stored in different layers. It is extremely inefficient in terms of data storage because data must be stored redundantly. Snapshot approaches result in a large amount of data duplication with unchanged properties in space and time. They are just a little more then a method for data collection, without advancing the analytical capabilities of the GIS.
In this model the spatial domain is fixed and the attribute domain is variable. It is based

on a linear, absolute, discrete time. It supports only valid time and multiple granularity. (Kainz, 2004)

Base state with Amendments Model

The *Base state with Amendments Model* uses an initial base state layer with the earliest time, included in the database. Then any changes from this layer are stored. To get the events or features for a given time period the base state is sequentially changed by the amendments until the required date is achieved. It represents changes as boundaries of states.

Compared with the *Sequential Snapshot Model*, this model reduces the amount of stored

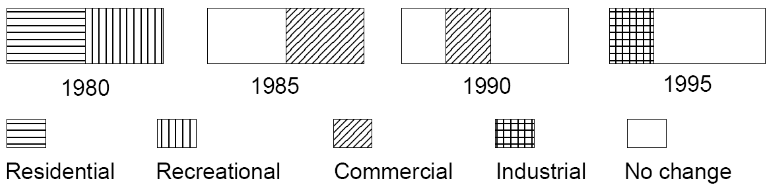


Figure 3.3: Base state with amendments approach (Raza, 2001)

data. Less data redundancy and traceable features through time are obviously advantages of this model.

Space-Time Cube Model

This model represents a three-dimensional cube with two space (spanned by the x- and y-axis) and one time dimension (along the z-axis). Traces of objects through time create a worm-like trajectory in the space-time cube. Data are accessed by referencing a point, tracing a vector, slicing a cross-section. This is a common CAD solution to deal with three dimensional objects. (Halls and Miller, 1996)
The attribute domain is kept fixed and the spatial domain variable. It is based on absolute, continuous, linear, branching and cyclic time and supports only valid time. (Kainz, 2004)

Space-Time Composite Model

The *Space-Time Composite Model* (figure 3.4) is similar to the *Base state with Amendments Model* but it stores the amendments in the same database. The space-time composite is produced by overlapping all time-stamped layers to generate a space-time composite layer. Nothing in the database is ever deleted, both past and present data are stored in

the same layer. Each record is assigned with time-stamps, having beginning and ending dates recorded as attributes. (Freelan, 2003)
It combines the separate GIS layers of the snapshots into a single one with all changes that occurred. (Langran and Chrisman, 1988; Langran, 1992b)
This approach is able to record temporality of attribute, space and time (i.e. changes) but fails to record temporality among attributes across space (i.e. motion).

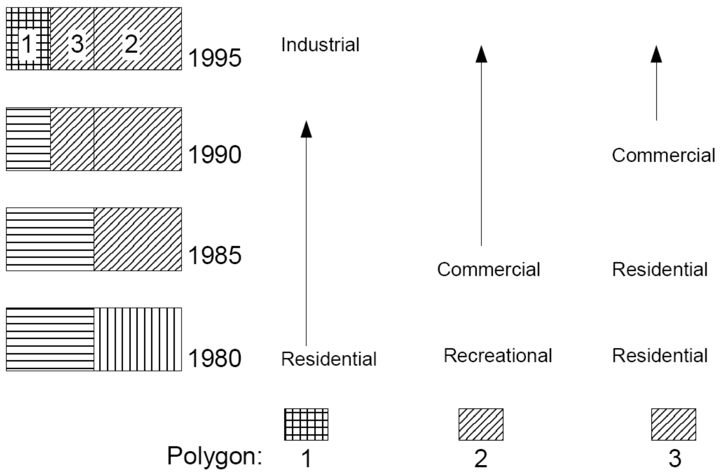


Figure 3.4: Space-Time Composite technique (Raza, 2001)

The *Space-Time Composite Model* is based on linear, discrete, relative time. It supports both valid and transaction time, and multiple granularity. It keeps the attribute domain fixed and the spatial domain variable. (Kainz, 2004)

Spatio-temporal Object Model

Worboys (1992, 1994) proposed the *Spatio-temporal Object Model*. The world is considered as a set of discrete objects. The objects are represented as two-dimensional spatial objects with the event-time as third dimension. The spatio-temporal objects (ST-objects) are a complex of spatio-temporal atoms (ST-atoms), both with a spatial and a temporal extent. Like the figure 3.5 shows the spatio-temporal objects are a collection of disjoint prisms, the ST-atoms. The bases of the prisms demonstrate the spatial extent and their heights represent their temporal extent.
The spatial-temporal atoms are the largest homogeneous units where the properties are hold in space and time. (Yuan, 1996)
This model is similar to the *Snapshot Model* and *Space-Time Composite Model*, represent-

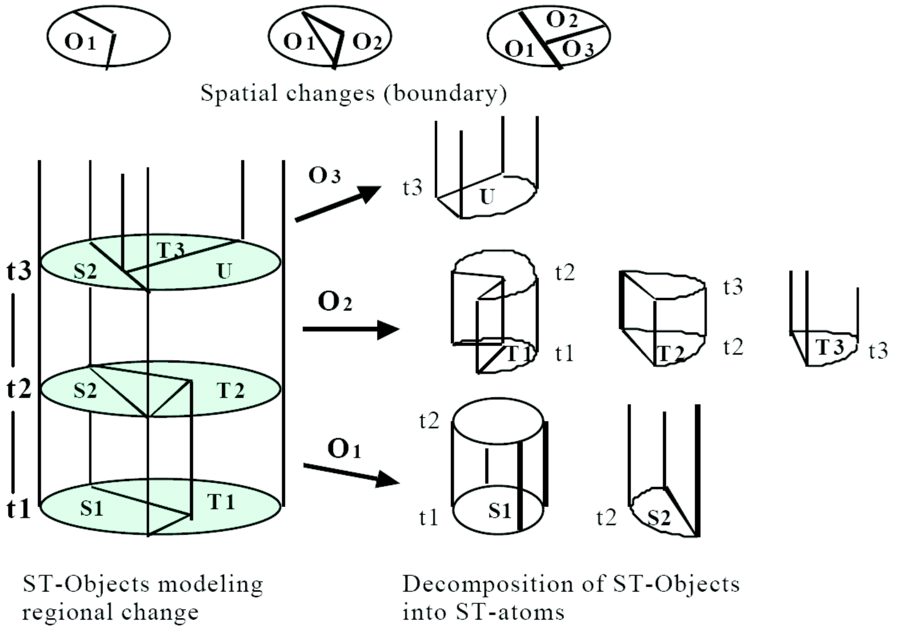


Figure 3.5: Spatio-temporal Object Model with ST-atoms (Worboys, 1992)

ing sudden changes upon an independent, discrete and linear time structure. (Liou, 1999). It supports valid and transaction time as well as multiple granularity. (Kainz, 2004)

Event-based Models

Peuquet (1994) developed the *Triad Model* including three separate linked models (location-, feature- and time-based). She suggests that feature-based models are more effective for the query and retrieval of information about objects. Location-based models are more effective for the query and retrieval of information about locations. Time-based models are more effective for the query and retrieval of information about time and changes through time.

Peuquet and Duan (1995) propose a raster-based, *Event-oriented Spatio-temporal Data Model* (ESTDM) based on the Triad database framework presented of Peuquet (1994). This model organises spatio-temporal information about locational changes. It uses a collection of time-stamped layers to represent temporal information from an event, starting with an initial state. When a change occurs an event entry is recorded and associated with a list of event components to indicate where changes occurred. The ESTDM has a header file with a pointer to the base map and pointers to the first and last event list.

The advantages are capability and efficiency to support spatial and temporal queries. A problem of the ESTDM is its adoption to a vector-based system, which requires a substantial redesign of event components. (Yuan, 1996)

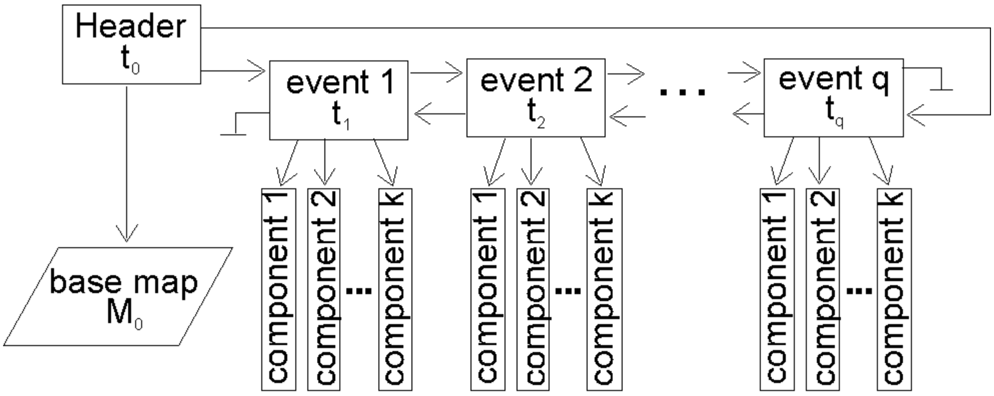


Figure 3.6: Elements and pointer structure of an ESTDM (Peuquet and Duan, 1995)

This is a time-based model. The thematic and spatial attribute domains are secondary. The model is based on discrete, linear, relative time and supports only valid time and multiple granularity. (Kainz, 2004)

Three Domain Model

Yuan (1994) describes the *Three Domain Model* for spatio-temporal modelling, which is based on semantic, time and space domains. Semantic, temporal and spatial objects are defined separately. They are linked to describe geographical phenomena (figure 3.7). In this model time is an independent concept instead of being an attribute of location as in the *Snapshot Model* or an integrated part of spatial entities as in the space-time composite and spatio-temporal objects.

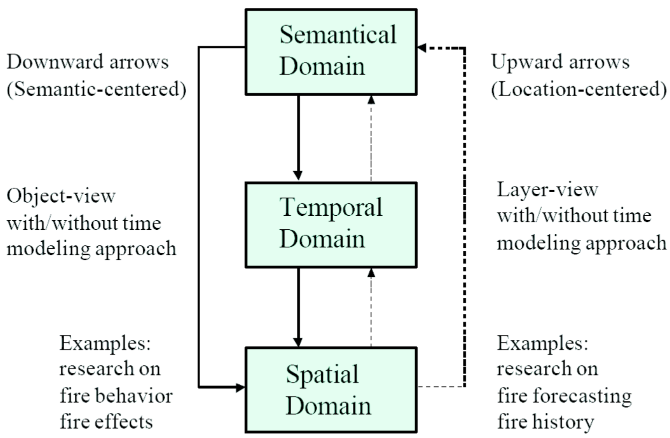


Figure 3.7: Conceptual framework of three domain models (Yuan, 1994)

Static and dynamic spatial changes can be modelled by dynamic linking the objects with the perspectives location-centred, attribute-centred and time-centred. (Nadi and Delavar, 2003)
The advantage of this method is that there are no predefined data schema and because it links dynamic the relevant objects of the three domains. (Yuan, 1996)
The major drawback is a missing identifier for temporal and spatial objects, important to keep track of the history of the objects. (Kainz, 2004)

3.2.2 Aspatial Change

Many concepts were developed to represent temporal changes in attributes. With each change in the database a new version of the information is generated, called versioning/time-stamping. In relational databases information is organised in several connecting tables. New versions for tables, records or attributes can be produced. Viz, versioning at table-level, record-level or attribute-level requires a connection of a set of time-stamps with the entire table or with each row or each attribute in a table. (Zhao, 1997)
There are three basic methods of recording temporal data commonly referred to as relation-level, attribute-level and tuple-level. (Langran, 1992b; Zhong and Dingqiang, 1996)

Versioning at relation/table level

The method of time-stamping at the relation level creates and stores a new snapshot of a table when an attribute change. In other words, it simply time-stamps each relation. This results in a high degree of duplication, especially when only a few records changed. Database operations like queries are simple since an entire database table is based on a given time slice. This method is analogous to sequential snapshot in spatial change. (Zhao, 1997; Heo and Adams, 1997)

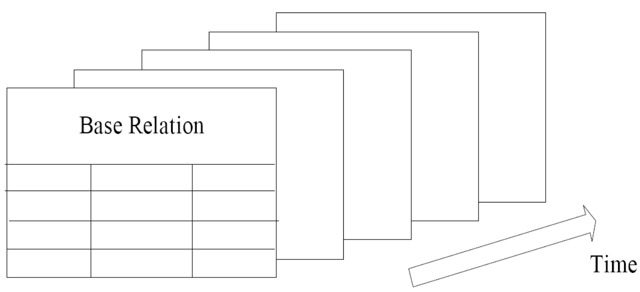


Figure 3.8: Time-stamping at relation level (Heo and Adams, 1997)

Versioning at record/tuple level

Versioning at record level reduce the degree of duplications by keeping track of 'since - until' time-stamps for each object. This is done by adding two new attributes to the records. But data duplication is still not completely avoided. If only some information of an record change, the entire record will be replicated, so that the not changed objects are duplicated. The drawback is that a query requires more processing time. (Zhao, 1997; Heo and Adams, 1997)

ID	Owner	Area	etc....	Since	Until
1	Mezera	1000		-	-
2	Smith	2000		-	1987
3	Benson	3000		1983	-
4	Chou	4000		1990	1996
5	Dewitt	5000		1933	-

Figure 3.9: Time-stamping at tuple level (Heo and Adams, 1997)

Versioning at attribute level

At attribute level temporal entities are represented by two relations instead of one: one holds the actual state, the other one all the history records as a linked chain. This method separates the time-variable and the non time-variable attributes, using a storage as little as possible. This results in the most compact database. In comparison to the other two models it can handle attribute change efficiently. The disadvantage is the space and time trade off. (Zhao, 1997; Heo and Adams, 1997)

ID	Non-time varing	Code
1		1
2		-
3		5
4		7
5		9

Code	Time varing	Since	Until	Next
1		-	1982	3
2		-	1987	5
3		1983	1989	--
4		1990	1996	10
5		1988	-	-

Figure 3.10: Time-stamping at attribute level (Heo and Adams, 1997)

3.3 Modelling in GIS

GIS modelling can take place in a GIS or require linking of a GIS to another computer program. There are three methods of integrating models into the GIS framework. (Wesseling et al., 1996)

- Loose coupling: at this approach GIS and model are separate, combining the capabilities by transferring files through a file exchange mechanism. For example, if statistics needs to be run, the data are exported from the GIS software for use within a statistical software and then reimported into GIS. So, existing models can be used immediately.
- Tight coupling: with the tightly coupled strategy the exchange of data between GIS and model is automatic and gives them a common interface. Custom-created menus in the GIS allow to run the model outside of the GIS. The model has to be changed in the way that input and output of the data are compatible with the GIS. Model and GIS can be run simultaneously and they are linked directly through sharing a common database.
- Embedded coupling: in this case GIS and model share a common interface and memory. The model has to be written in the programming language provided by the GIS or a GIS has to be added to the modelling system. This of course is only possible when the GIS supports all necessary operations required by the model and when it provides a programming language in which the model can be coded.

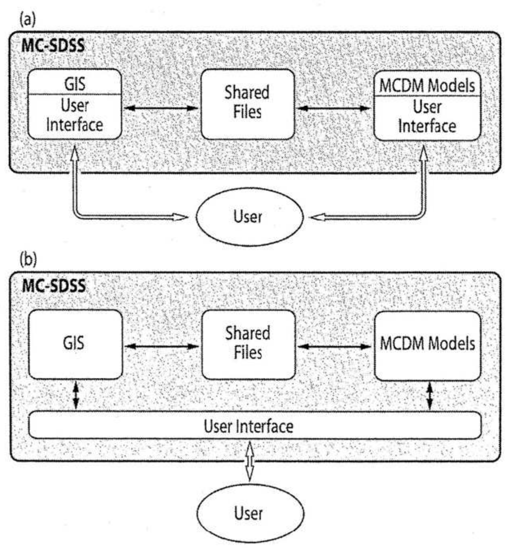


Figure 3.11: Loose (a) and tight (b) coupling strategies (Malczewski, 1999)

Chapter 4

Project MANTA

4.1 Background

The commissioner of the government delegated to the water traffic in the Venice lagoon authorised the 'Consorzio Venezia Ricerche' to develop a dynamic mathematical model for the representation of the water traffic in the historical centre of Venice.
A multi discipline working group was arranged for the realisation of this project, consisting of scientists of the department of applied mathematics of the University of Venice, the company Thetis Spa and the society FormaUrbis as well as further experts. The developed simulation model for the traffic in Venice can be considered as a first step for the development of a decision support system based on GIS. The project was called MANTA - 'Modello d'ANalisi del Traffico Acqueo' that means 'Model for the Analysis of the Water Traffic'.

A possible application of this system is the decision support in offices and institutions for traffic planning. The system offers among other things a simulation of the traffic and the production of traffic statistics.
The model is conceived in such a way that the data can be updated sequentially, whereby it is made possible to reach better and better consistency with the real situation and easier adaptation to changing traffic-regulations.

The model represents an autonomous system and is connected with GIS by a common database, in which they divide the data (figure 4.1). The GIS (ArcGIS) administers the geodatabase of the traffic network, thus geometry of the graph and the associated data. It permits the analysis and visualisation of the produced results of the traffic-model.

The traffic model and GIS are part of two different operational modules: the simulator

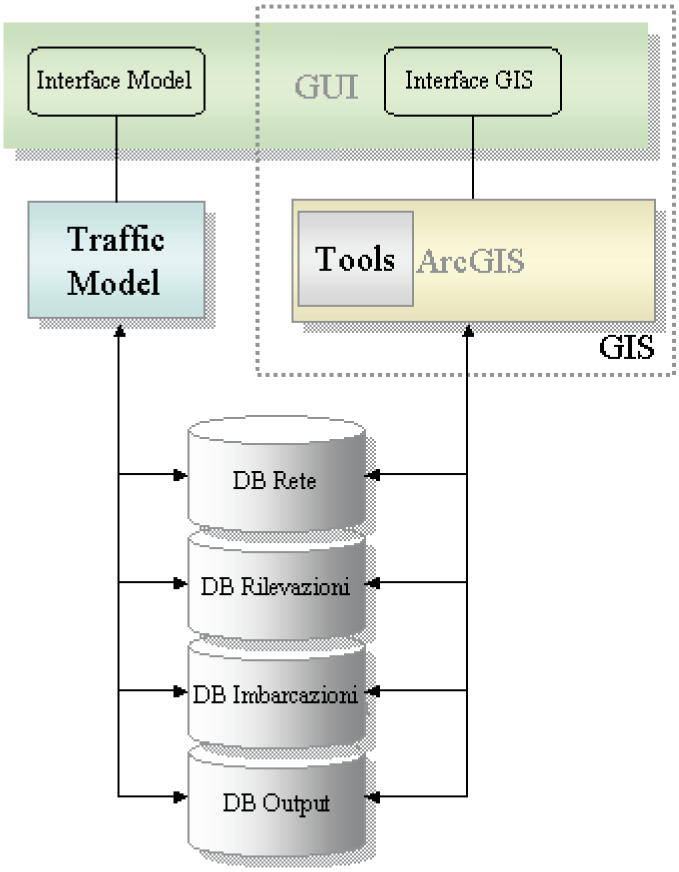


Figure 4.1: Scheme of the modules of the GIS for the simulation of the traffic (Source: CVR)

produces the necessary scenarios which afterwards can be visualised and evaluated in the GIS. So it is about loose coupling (see section 3.3).
The GIS permits the user the dynamic visualisation of the results (movement of the boats, variation of arcs and nodes, alphanumeric values associated with arcs and nodes), the analysis of the data (call of video, diagrams and tables) and the local modification of parameters of the graph for the simulation of the scenarios (figure 4.2).

In the following list the criteria involved in the modelling are enumerated:

- maximum width of a boat to be allowed to navigate through a channel (figure 4.3)
- direction of motion in the channels
- permission whether motorboats may navigate in a channel
- the maximum allowed tonnage of a boat in the channels (figure 4.4)
- the maximum allowed speed in the channels (figure 4.5)

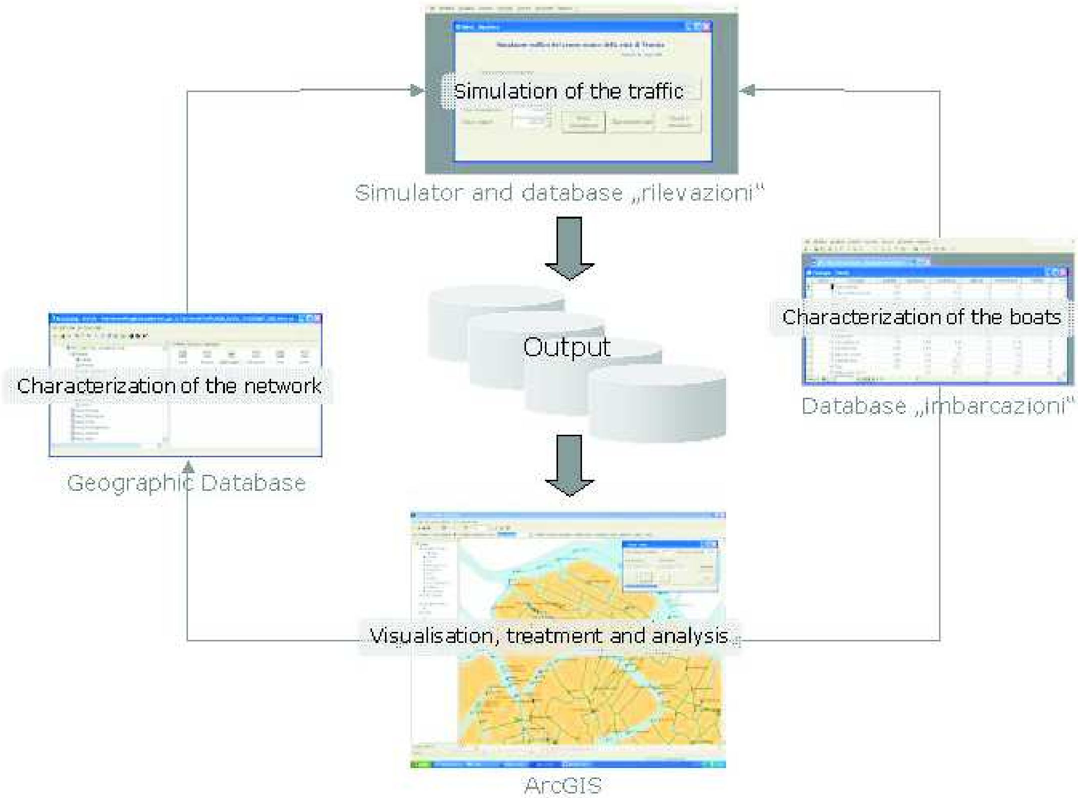


Figure 4.2: Structure of the application MANTA (Source: CVR)

Some of these characteristics are shown in the figures 4.3, 4.4, 4.5.

The data of the project are the basis for the application MOON. Not only the different basic layers, like the islands, channels, channel network, data of channel depth etc. but also the data output from the traffic simulation. In the next sections this data will be described a bit more in detail.

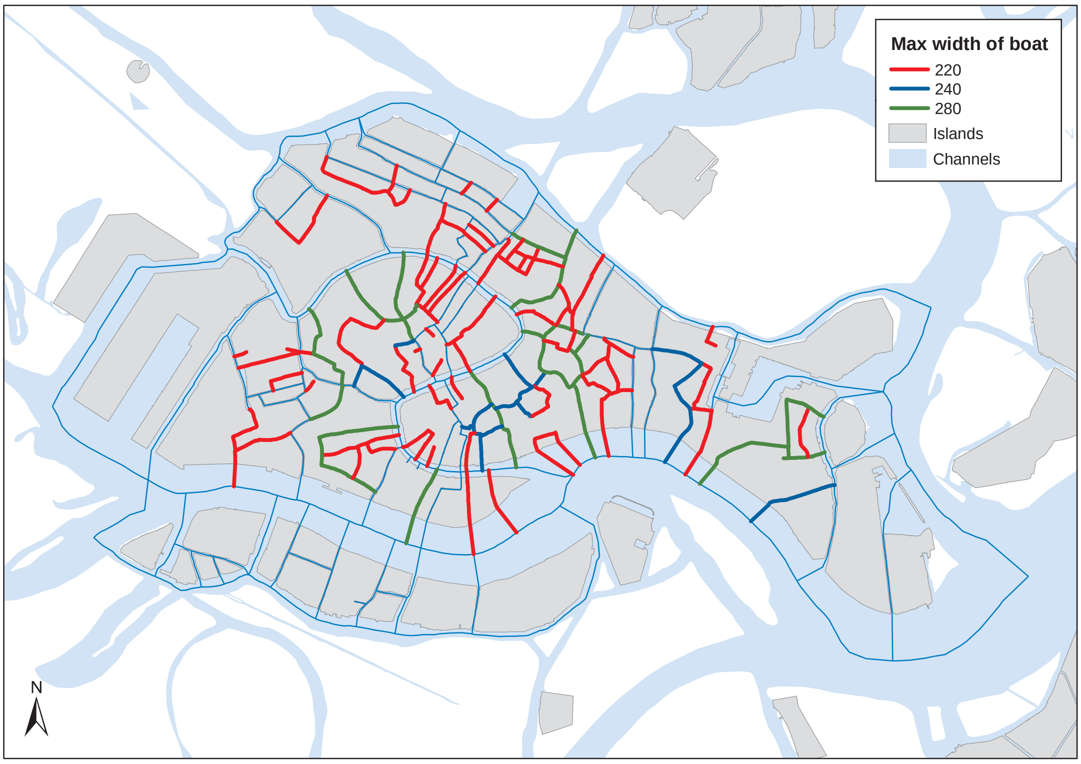


Figure 4.3: Maximum allowed width of the boats

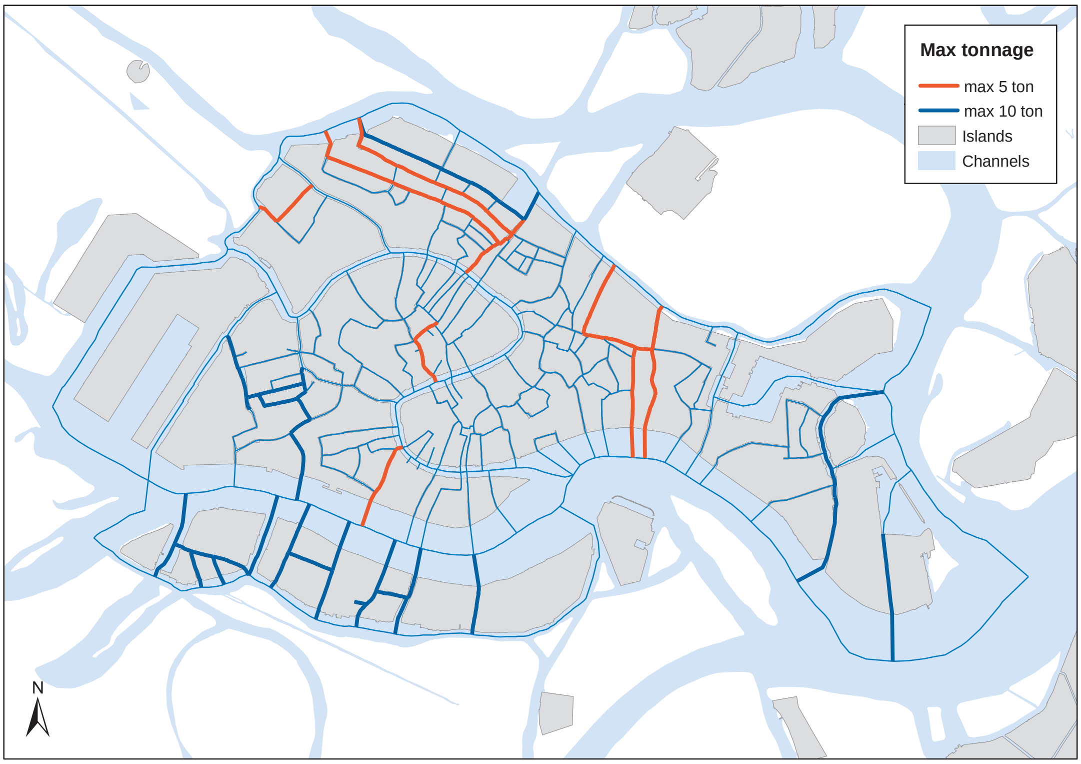


Figure 4.4: Maximum allowed tonnage of a boat

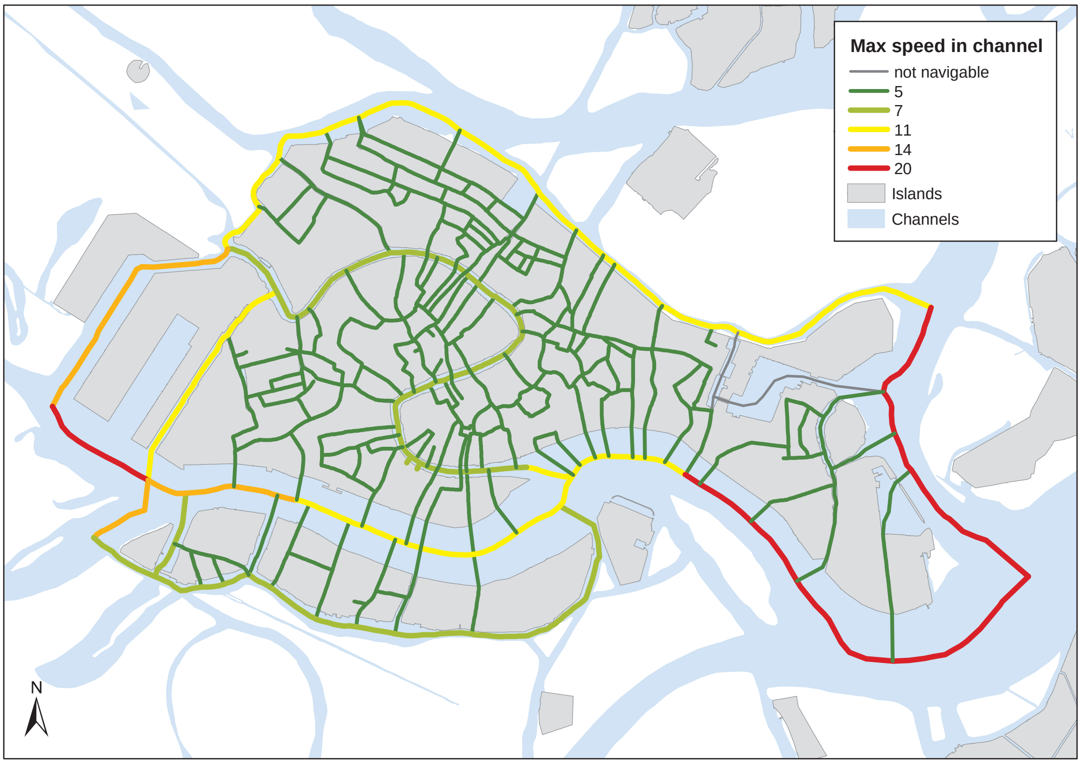


Figure 4.5: Maximum allowed speed in the traffic network

4.2 Traffic Network

The channel network is represented through arcs and nodes. The arcs, in the model named segments, are line objects (polylines). The nodes are point objects and represent bridges ('ponti'), stops ('fermate') and narrowing ('restringimenti') in the channel.
The intersections (nodi_intersezione, NI) are fundamental elements for the modelling of the channel system. They represent intersection points, points of which two or more arcs meet.
Beside these intersections (NI) further punctual objects, so-called pseudo-nodes were produced. They represent the bridges (Nodi_Ponte, NP), narrowings (Nodi_Restringimento, NR) and stopping places (Nodi_Fermata, NF) in the channel network (figure 4.6).
These and further data were stored in a relational database (MS ACCESS).

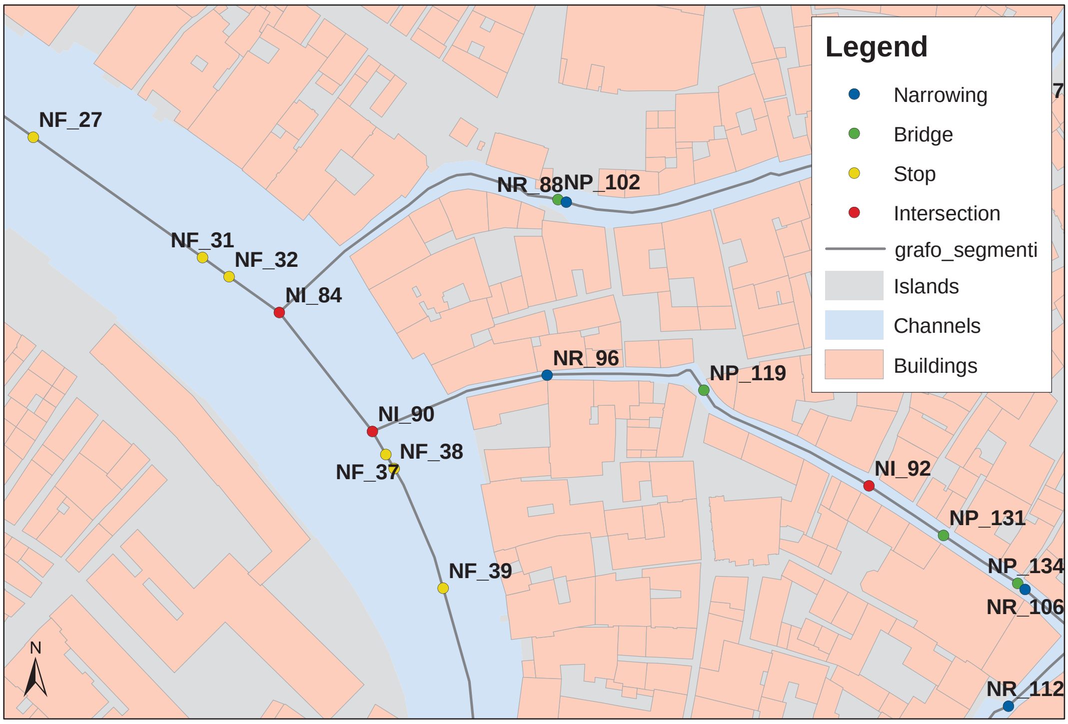


Figure 4.6: Details of the traffic network

Geodatabase of the Network The database of the channel network contains geometrical data like the channel network and the basic layers and alphanumeric data, like the table of the nodes. A Personal Geodatabase was produced (relative file rete.mdb). The spatial data of the geodatabase are administered directly over ArcGIS, while the non-spatial data can be used also with ACCESS. The database contain a Feature Dataset called "Venezia", which contains the features of the geographical working area (figure 4.7.

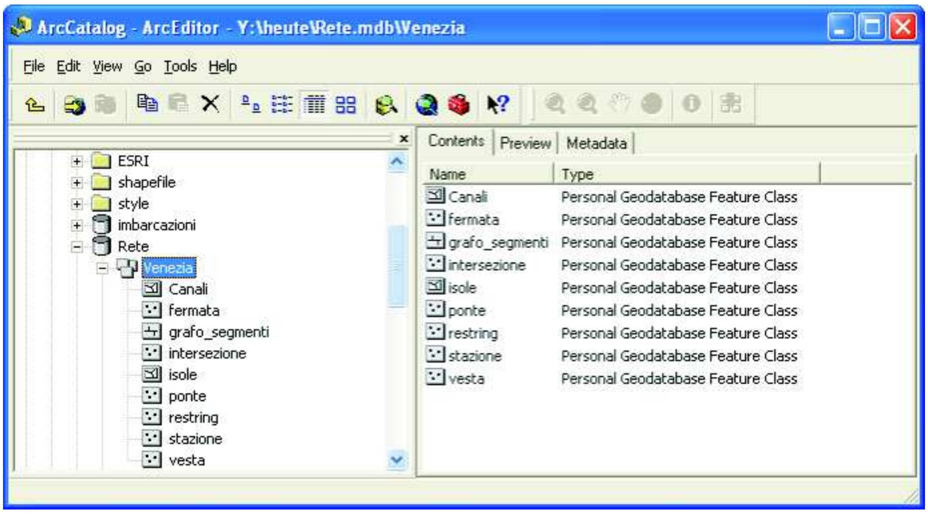


Figure 4.7: Feature Dataset in Rete.mdb

Structure of the Traffic Network The conceptional model requires an explicit connection between the nodes and segments. At the beginning of the database development only implicit topology between the nodes and segments existed, but no logical structure which connected both entities geometrically. The data model (spatial and attribute data) must differentiate between the entity with geometrical structure (static, e.g. the segments) and the entity that represents the attributes (dynamic, e.g. the pseudo nodes, boats). This was realised with the dynamic segmentation, which links nodes (intersections), segments and pseudo nodes (bridge, stops and narrowings) logically.
The dynamic segmentation (in ArcInfo) defines the following components (figure 4.8): arcs (corresponding to the segments of the channel network), sections (1-2 section in every arc), routes (groups of sections), events (point or linear representation related to a segment of the route).
The dynamic segmentation uses an event table to visualise the data. The event table contains records, so-called events, which have a certain position (location), in this case the nodes and pseudo nodes along the segments.

4.3 Database of the Boats

The database of the boats contains all data concerning the different boat types, which are used in the model. The characteristics of the individual types are stored in the table 'Tipologie' (figure 4.9). This table includes among other things the dimensions of the

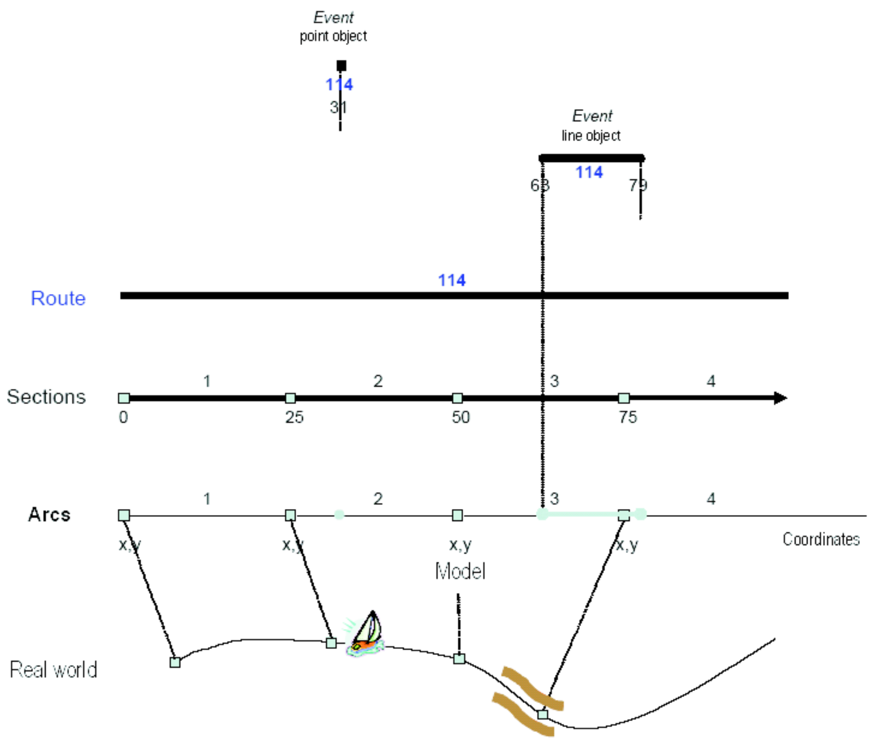


Figure 4.8: Data model of the dynamic segmentation (Source: CVR)

boats as well as their maximum and medium speed. In addition the maximum number of boats which can arise in the system are indicated. 17 different boat types were specified. This classification turns out to be inaccurate for the calculation of the 'moto ondoso', because the wave production depends strongly on the boat characteristics.

4.4 Simulation Model

Like mentioned before the model is implemented in ACCESS. All data of the simulation is saved in the database simulator.mdb.
The structure of the network to be simulated consists of a net of channels that begin and end in intersections (NI). Along every channel bridges, stops and narrowings can be found. The main classes that compose the model are:

- 'Nodi' containing the intersections
- 'Pseudonodi' subdivided into the classes: bridges (ponti), stops (fermate) and narrowing (restringimenti)
- 'Segmenti' containing the channel segments from one intersection to the next

Tipologie : Tabella

Indice	Tipologia	Tip_AW	quantità	larghezza	lunghezza	altezza	immersione	VelMax	VelMedia
1	Topo grande	Topo_grande	100	4,3	20	1,6	1,4	15	8
2	Topo medio-piccolo	Topo_medio_piccolo	590	2,4	11,5	1,6	0,9	10	8
3	Topetta	Topetta	210	1,65	7,66	1,5	0,2	10	8
4	Topa	Topa	536	1,65	7,66	1,5	0,2	10	8
5	Zatterino	Zatterino	105	2,12	6,78	1,5	0,35	15	8
6	Cofano	Cofano	814	1,6	4	1,5	0,2	15	8
7	Barchino	Barchino	530	1,65	4,06	1,5	0,15	15	8
8	Patana	Patana	127	2	7,7	1,5	0,4	15	8
9	Patanella	Patanella	286	2	7,7	1,5	0,4	15	8
10	Cacciapesca	Cacciapesca	89	1,54	4,9	1,5	0,16	15	8
11	Sampierota	Sampierota	438	1,62	6	1,5	0,25	15	8
12	Barca a remi	Barca_a_remi	420	0,9	12	1,5	0,3	5	2
13	Granturismo	Granturismo	100	3,9	22,3	1,8	1,2	28	10
14	Taxi	Taxi	320	2,3	9,01	1,6	0,8	40	10
15	Motoscafo ACTV	Motoscafo_ACTV		3,4	21,1	2,8	0,97	20	8
16	Vaporetto ACTV	Vaporetto_ACTV		4,22	22,95	3	1,39	24	8
17	VESTA	VESTA	30	2,5	11,75	1,6	0,6	15	8

Record: 1 di 22

Figure 4.9: Table 'tipologie'

– 'Imbarcazioni' containing the characteristics of the various boat types

The events generated by the simulator regard the arrival and the departure of a boat in a node. Generally an event of arrival in a node involves a successive event of departure from the same node and vice versa.

The presence of various boat types allows to differentiate the behaviour of the same ones. The various treatments relate to e.g. physical characteristics of the system, like segments that are only navigable for some of the 17 boat types.

The created table 'Archivi_eventi' stores all the events of one simulation in chronological order. To make the dynamic visualisation possible this data is also saved in a transformed way in the table 'PosizioniID'- it contains the position of the boats in the system at predefined time intervals (figure 4.10).

Microsoft Access - [PosizioniID : Tabella]

File Modifica Visualizza Inserisci Formato Record Strumenti Finestra ?

OBJECTID	Tipologia	Indice_tipologia	tempo	Codice_Seg	Distanza
2213156	Topo medio-piccolo	2	31/12/1899 7.10.00	ARZE01	112,6133
2213105	Topo medio-piccolo	2	31/12/1899 7.10.00	GIRO01	75,4473
2207653	Taxi	14	31/12/1899 7.10.00	SCOM02	55,12995
2213104	Topo medio-piccolo	2	31/12/1899 7.10.00	GRAN01	86,07111
2207660	Taxi	14	31/12/1899 7.10.00	LAVR01	315,7429
2216514	Zatterino	5	31/12/1899 7.10.00	GRAN31	51,86062
2216513	Zatterino	5	31/12/1899 7.10.00	SCOM01	149,5693
2213106	Topo medio-piccolo	2	31/12/1899 7.10.00	ANDR02	37,25678
2216511	Zatterino	5	31/12/1899 7.10.00	GRAN03	73,43744
2210770	Topo grande	1	31/12/1899 7.10.00	CREA01	77,74655
2213102	Topo medio-piccolo	2	31/12/1899 7.10.00	RAFF01	57,25412
2213101	Topo medio-piccolo	2	31/12/1899 7.10.00	GIUD07	22,68177

Record: 1 di 10760

Visualizzazione Foglio dati NUM

Figure 4.10: Table 'PosizioniID'

User Interface of the Simulator The user interface of the simulator previews a main template that allows to insert the most important parameters for the simulation: to start the simulation and to recall other windows for the modification of the advanced settings. The temporal interval of the simulation can be set in the main menu with starting and ending time. With these parameters the output of the positions of the boats may be created in the database (figure 4.11).

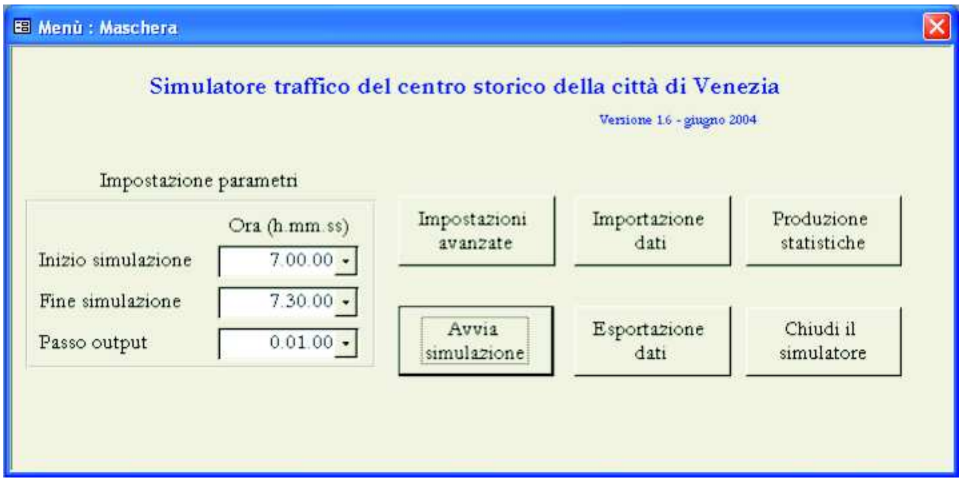


Figure 4.11: Main menu of the simulation module

In the advanced settings (figure 4.12) among other things the seed for the generator (accidental numbers) and the duration of the transitory period can be chosen. The transitory

Figure 4.12: Advanced settings of the simulation module

period is the time in which the simulator makes its calculations without information input of the traffic. This is necessary in order to get the net in a situation of departure in which the boats are distributed on the entire net.

During the development of the simulation, the events, in which possible alternatives exist, are guided according to directives and with the use of a generator of pseudo accidental numbers.
In the right part of the mask, parameters for the tide can be set. It is supposed that a day has two maximum and two minimum peaks of tide levels. The values of the peaks (in centimetres) as well as the time when there is the first maximum can be set.

4.5 Visualisation in GIS

For the dynamic visualisation in ArcGIS 8 an extension was developed with ArcObjects. The customer can load this module inside ArcGIS to supply new functionality using the data output of the simulation model.
The extension can be used to represent and analyse the results of the simulation model and the characteristics of the channel network. One functionality is the dynamic visualisation of the traffic movements for a given time interval, depending on the starting and ending time used in the traffic model.

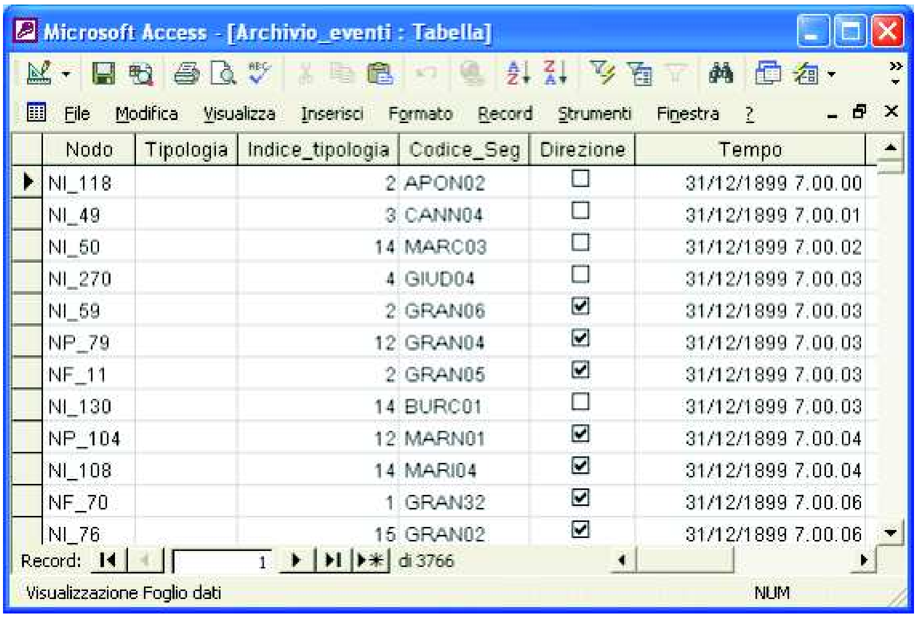
4.6 The Factor Time

The maximum time interval which can be simulated in the model is one day, because MANTA was developed to visualise the changes of the traffic during a one day period.
The granularity, the smallest time interval to be represented, is one second ('Archivi_eventi'). Real-time application require fine time granularity (down to minutes and seconds), while for long term planning a granularity of month or years are sufficient.
The information has the following dynamic aspects: positional changes regarding the movement of the boats but no geometrical changes (see section 3.1).

To integrate time into GIS the attributes are time stamped. The time is saved as an attribute, representing the valid time, the time when the event occurs in the world. Transaction time is not specified. Therefore the database can be defined as historical database, which describes the history of the objects from today's view (see section 3.1).

The approach of the project MANTA to realise time aspects in GIS can be categorised as versioning or time-stamping technique at record or tuple level. The difference to the explanation given in section 3.2.2 is that no 'since - until' time stamps (states) are stored just the time points of the events (see figure 4.13).

The historical database and the implemented tool for dynamic visualisation, demonstrate



Nodo	Tipologia	Indice_tipologia	Codice_Seg	Direzione	Tempo
NI_118		2	APON02	☐	31/12/1899 7.00.00
NI_49		3	CANN04	☐	31/12/1899 7.00.01
NI_50		14	MARC03	☐	31/12/1899 7.00.02
NI_270		4	GIUD04	☐	31/12/1899 7.00.03
NI_59		2	GRAN06	☑	31/12/1899 7.00.03
NP_79		12	GRAN04	☑	31/12/1899 7.00.03
NF_11		2	GRAN05	☑	31/12/1899 7.00.03
NI_130		14	BURC01	☐	31/12/1899 7.00.03
NP_104		12	MARN01	☑	31/12/1899 7.00.04
NI_108		14	MARI04	☑	31/12/1899 7.00.04
NF_70		1	GRAN32	☑	31/12/1899 7.00.06
NI_76		15	GRAN02	☑	31/12/1899 7.00.06

Figure 4.13: Event table 'Archivi_eventi'

a first step toward spatio-temporal GIS that can retrieve and display change patterns. But a temporal GIS is composed of three general parts: a temporal database, temporal visualisation and temporal analysis. In the approach of MANTA a function for analysing changing patterns is missing, due to the fact that it was a no postulated function. A possible analysis could be to compare the change patterns of traffic counts between GIS layers: GIS layers of different time intervals could be compared with an implemented analysis tool. A similar application is presented by Shaw (2000).

Chapter 5

Application MOto ONdoso

On basis of the before described data and simulation model of the traffic in the historical centre of Venice, including further information, an application for the estimation of the boat-generated waves in the channels of Venice was developed.
A possible application of this study will be in the extension of the project MANTA. Then further factors should be included, which are momentary ignored. In general the information of "when", "where" and "by whom" the waves are produced are useful for possible future traffic regulations and/or changes. The results could also help to decide which channels or channel sections should be inspected more often for damages.

The 'moto ondoso' is a much discussed topic in Venice, however so far a useful model to realisticly represent and evaluate the wave generation is still missing. There are different measurements and also a formula for calculation of the 'moto ondoso' in the open lagoon, but calculation methods particularly for the historical centre of Venice are missing. That is understandable due to the fact that there is a high complexity of interacting factors like the channel characteristics (depth, width, material ...), the different boat types (dimension, engine strength, material, ...) etc. The boat-generated waves cause over a longer period damages on the foundations of Venice (section 2.5). The re-establishment/restoration of these damages is very time-consuming, cost-intensive and put the houses at risk. Therefore this topic is not only relevant for the municipality of Venice but also for their inhabitants. It is a difficult rank between mobility and protection of Venice. Without the boat traffic the city would be paralysed but too much traffic again has a destructive factor - which many do not want to admit.

With the processed data output of the simulation model of the project MANTA and by means of a formula (section 2.2) for the determination of the maximum wave height produced by a boat, the 'moto ondoso' will be defined.

5.1 Preparation of the Data

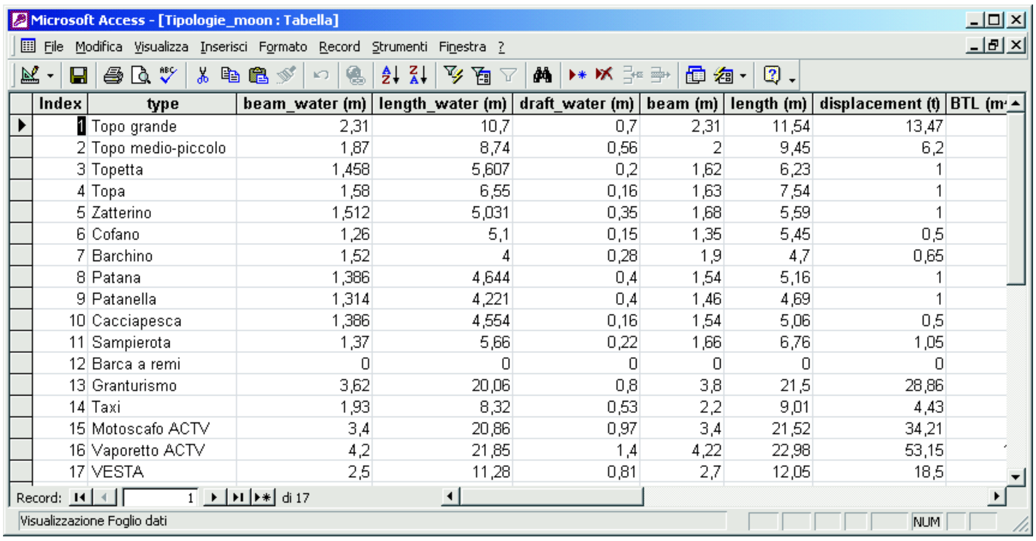
The implementation to realise a temporal analysis of the 'moto ondoso', dependent on the boat traffic in the historical centre of Venice, will be carried out in the following section. Before presenting the realisation of the application MOON some important consideration concerning the data and the calculation of the 'moto ondoso' has to be done.

What kind of data is necessary? First it was important to get an overview of the factors which affect the 'moto ondoso'. A list of the different circumstances which influence the wake waves can be found in section 2.1.3. Boat related factors and environmental related factors are necessary.

Does the existing data fulfil this requirements? The data of the project MANTA are divided in three databases (Rete.mdb, Imbarcazioni.mdb, Simulatore.mdb). Boat related data are stored in the table 'tipologia' of the database Imbarcazioni.mdb. Possible information about environmental related data (related to the segments) can be found in table 'grafo_segmenti' of the database Rete.mdb.

How can the 'moto ondoso' be computed from these data? Particularly for the situation of Venice there are still no formula existing.
After intensive searching and comparisons the formula of Kriebel (2003), developed by the US Naval Academy for the calculation of the maximum wave height, was selected. This formula was developed for large displacement hulls and could be unsuitable for the situation in Venice. However only formulas for large ships were found, none for boats like those in Venice. The choice fell on the formula of Kriebel (2003) because it takes many important aspects into consideration, which influence the wake waves. Among other things the water depth and the distance from sailing line are important to include into the calculations regarding the channels of Venice.
Following information are used in the calculations of Kriebel (2003):
Boat related: Ship speed (V ($\frac{m}{s}$)), ship length (L_s (m)), ship length at waterline (L_{wl} (m)), entrance length (L_e (m)), draft (T (m)), ship width/beam (B (m)), displacement (D (t))
Environment related: water depth (d (m))
Others: distance form sailing line (y (m)), acceleration due to gravity (g (m/s^2))

It turned out that essential data for the calculation of the formula was missing in the database imbarcazioni.mdb. These could however be supplemented by more detailed data of Zotti (2002). Comparing the requested boat related data with the existing data in table 'Tipologie' (figure 4.9) the following necessary informations are missing: ship length at waterline (L_{wl} (m)), entrance length (L_e (m)) and displacement (D (t)). The table could be expanded with data from Zotti (2002) (figure 5.1). The entrance length can be calculated with 90% of the normal ship length.



Index	type	beam_water (m)	length_water (m)	draft_water (m)	beam (m)	length (m)	displacement (t)	BTL (m
1	Topo grande	2,31	10,7	0,7	2,31	11,54	13,47	
2	Topo medio-piccolo	1,87	8,74	0,56	2	9,45	6,2	
3	Topetta	1,458	5,607	0,2	1,62	6,23	1	
4	Topa	1,58	6,55	0,16	1,63	7,54	1	
5	Zatterino	1,512	5,031	0,35	1,68	5,59	1	
6	Cofano	1,26	5,1	0,15	1,35	5,45	0,5	
7	Barchino	1,52	4	0,28	1,9	4,7	0,65	
8	Patana	1,386	4,644	0,4	1,54	5,16	1	
9	Patanella	1,314	4,221	0,4	1,46	4,69	1	
10	Cacciapesca	1,386	4,554	0,16	1,54	5,06	0,5	
11	Sampierota	1,37	5,66	0,22	1,66	6,76	1,05	
12	Barca a remi	0	0	0	0	0	0	
13	Granturismo	3,62	20,06	0,8	3,8	21,5	28,86	
14	Taxi	1,93	8,32	0,53	2,2	9,01	4,43	
15	Motoscafo ACTV	3,4	20,86	0,97	3,4	21,52	34,21	
16	Vaporetto ACTV	4,2	21,85	1,4	4,22	22,98	53,15	
17	VESTA	2,5	11,28	0,81	2,7	12,05	18,5	

Figure 5.1: Table 'tipologie_moon'

Another uncertainty represents the data of the channel depth. The existing data does not describe the current depth, but the planned situation. It concerns data of INSULA Spa, which represents the depth of the channels after unsilting. The major disadvantage is that some channels will not be unsilted and therefore the pertinent segments have the value zero. Thus these channels could not be referred into the computations.

Both middle and maximum speed of the boats is stored in table 'Tipologie' (Imbarcazioni.mdb) and in table 'grafo_segmenti' (Rete.mdb) the maximum allowed speed in the channels. The maximum speed of the boat will be compared with that of the segment and then the lower one is used for the evaluation.

The middle channel width (Rete.mdb) is divided by two to attain the computation of the distance from the sailing line.

The used traffic network has the drawback that in wide channels just one shipping lane is existing, but in reality many boats sail side by side (figure 5.2). Also in the case that there would be just one boat it does not necessarily sail exactly in the middle of the channel. The presence of more boats next to each other affect the wave generation and wavy lines. The waves break and reflect on other boats.

The perturbation of any boat interact with the already existing one of the water so that it becomes nearly impossible to understand the unproportional effects generated by many boats together. (Consorzio Venezia Ricerche, 2002)

The effects of acceleration, deceleration and manoeuvres have to be added as well (section

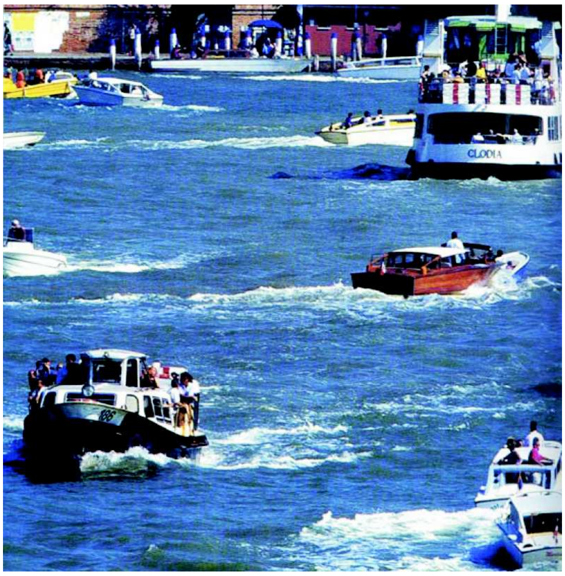


Figure 5.2: Boat traffic in wide channels (Source: CVR)

2.5), which amplifies the turbulences and generated waves. During these actions it is impossible not to reach the critical speed (see section 2.1.3).
At stops for the public transportation, taxis etc, wave production and turbulences are more intensive. Also intersections are influenced of these affects: deceleration with following acceleration or manoeuvres to turn into a side channel.

For a realistic estimation of the boat-generated waves still more factors have to be included, like the tidal currents, mentioned of Macfarlane and Renilson (1999) in section 2.1.3. Brighenti et al. (2003) name also the turbulences produced by the motors (section 2.5).

All these remarks regarding the generation of the 'moto ondoso' show that a realistic estimation is a difficult undertaking. Also when many of these important factors are not adopted in the calculation of the application MOON, they have to be mentioned for a better understanding and the later estimation of the results.

In the next step it had to be determined which table of the produced output can be used for the calculations. The table created for the dynamic visualisation is unsuitable. Therein the positions of the boats are stored e.g. with the interval of a minute whereby two problems occur: on the one hand the same boat can occur several times in one segment (dynamic segmentation) which however is not recognisable, because the individual boats are not stored as objects. Thus the value would be assigned several times to the same segment instead of just one time. On the other hand within one minute segments were jumped over by boats, thus the short segments would be ignored nearly completely from the evaluation.

But the table 'Archivio_eventi' can be used. Therein events, the occurrence of the boats, become registered second exact. Every time a boat passes a node or a pseudo node this is stored in the table. The events stored in this table indicate the change of a condition, represented as time points. The time depending objects are the boats and the temporal data is represented as events (3.1).

Since the application MOON is based on the data of the project MANTA, the temporal aspects are the same as described in section 4.6. But there is one difference: there are just attribute changes over time (value wave height) and no positional changes like at the application of MANTA. The spatio-temporal data models can be divided in spatial and aspatial changes (Zhao, 1997; Heo and Adams, 1997). The temporal changes presented by the application MOON can be categorised as aspatial changes.

5.2 Realisation

5.2.1 Calculations in MS ACCESS

At the beginning the simulation had to be run for a whole day, the maximum possible length. This was done for another four days with different seeds (section 4.4), to get a certain average value of the calculation. More days were not included because of the long duration of the simulation and the fast increasing data volume. After a run-through of one day, this table got saved separately because it is not possible to store more than one day in table Archivi_eventi. Finally the data of all five days were stored together.

The next paragraphs will go a bit more in detail in how the tables got modified and how the calculation of the wave height got implemented in ACCESS, with the help of queries. To give a better overview the figure 5.3 was elaborated.

The events saved through the simulator can be divided into four categories: an event in which a boat passed an intersection (NI), a bridge (NP), a narrowing (NR) or a stop (NF). This is visible at the ID in the column 'Nodo' (figure 4.13). Just the events at intersections are relevant.

First of all a query (Q0_creatab) was created to extract the intersection events and to store them in a new table with the name tab_start. In that table the boats with the index 12 got cancelled (Q_cancel12_moon), because this boat type represents rowing boats and is therefore irrelevant for the generation of the 'moto ondoso'.
Beside the table tab_start also the tables topologie_moon, grafo_segmenti_moon and tab_time will be used.

For a better understanding of how the formula of Kriebel (2003) was converted into queries, the parts of the formula which got calculated, will be written in brackets.
With the help of the queries Q_part1beta_moon ($0,45\left(\frac{L}{L_e}-2\right)$), Q_beta_moon ($1+8*(part2beta^3)$) and Q_alpha_moon ($\alpha = 2,35\,(1-C_B)$) the values of α and β got calculated. One part of the calculation of β had to be done in EXCEL, because ACCESS does not support tanh.
These queries have to run only once because the values are just depending on the boat characteristics and do not change any more.

To find out the speed, the maximum allowed channel speed got compared with the maximum speed of the boats and the lower one was chosen (Q_Vmax_moon). From figure 5.3 follows that this speed is necessary to calculate afterwards with Q_FroudeL_moon the length Froude number.

Then the results of the length Froude number and the value of α are used to calculate the modified Froude number $F*$ with query Q_Froude*_moon ($F_* = F_L \exp\left(\alpha \cdot \frac{T}{d}\right)$). This finally lead to query Q_tabend_moon ($\beta\,(F_* - 0,1)^2 \cdot \left(\frac{y}{L}\right)^{-\frac{1}{3}}$): The table tab_end contains the values of $\frac{g \cdot H}{V^2}$ resulting from the calculation with β and $F*$.

To be able to visualise this results in GIS the segments in table tab_end get grouped and the mean for $\frac{g \cdot H}{V^2}$ is calculated (Q1_index). Then with the use of the results of Q1_index the maximum wave height is calculated (Q1_waveheight). Q1_sumindex groups the segments and calculates the sum of $\frac{g \cdot H}{V^2}$.
Within the queries Q1_index, Q1_sumindex and Q2_barche an additional criterion is inserted to make it later possible to choose starting and ending time of a wanted time interval. Therefore the table tab_time is used.

To find out the share of the individual boat types on the wave generation, the table tab_end got grouped by segment and boat type and the values of $\frac{g \cdot H}{V^2}$ are summed (Q2_barche). Then every boat type (Q3_type1, Q3_type2, ...) got extracted separately, grouped by the segments. Finally all 16 tables are put together in one (Q4_CreaStat).

For running all queries in one step, a macro was created and a mask was drawn up with which the macro can be started. Starting and ending time has to be inserted to define the wanted time interval (see figure 5.4).

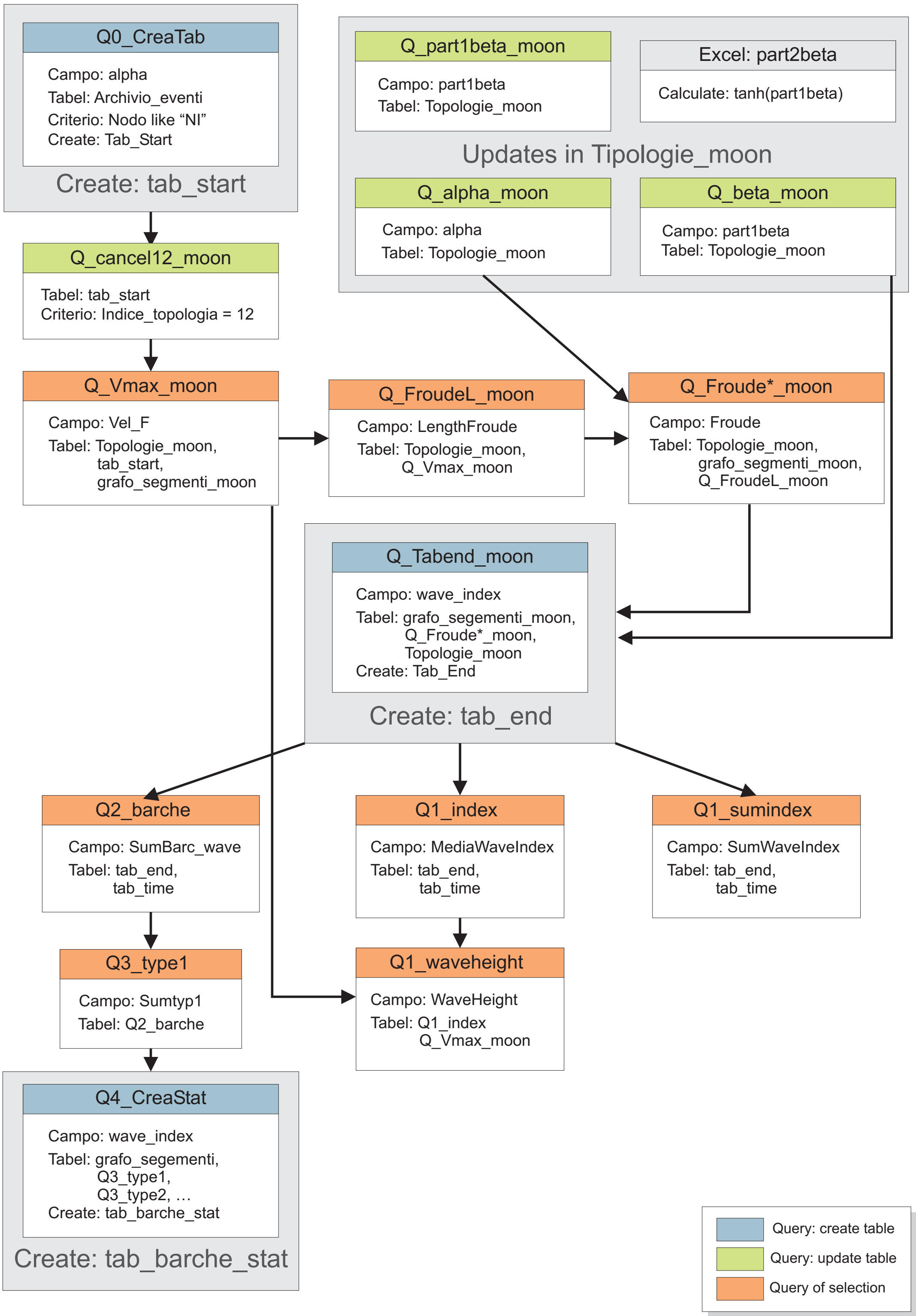


Figure 5.3: Model of the queries in MS ACCESS

5.2.2 GIS Setup

In GIS first the basic layers are added, consisting of the channels, islands and the traffic network.
A button was created to be able to launch the macro directly from within GIS and make possible the choice of a wanted time interval. With the refresh button in GIS then the actual data can be visualised.

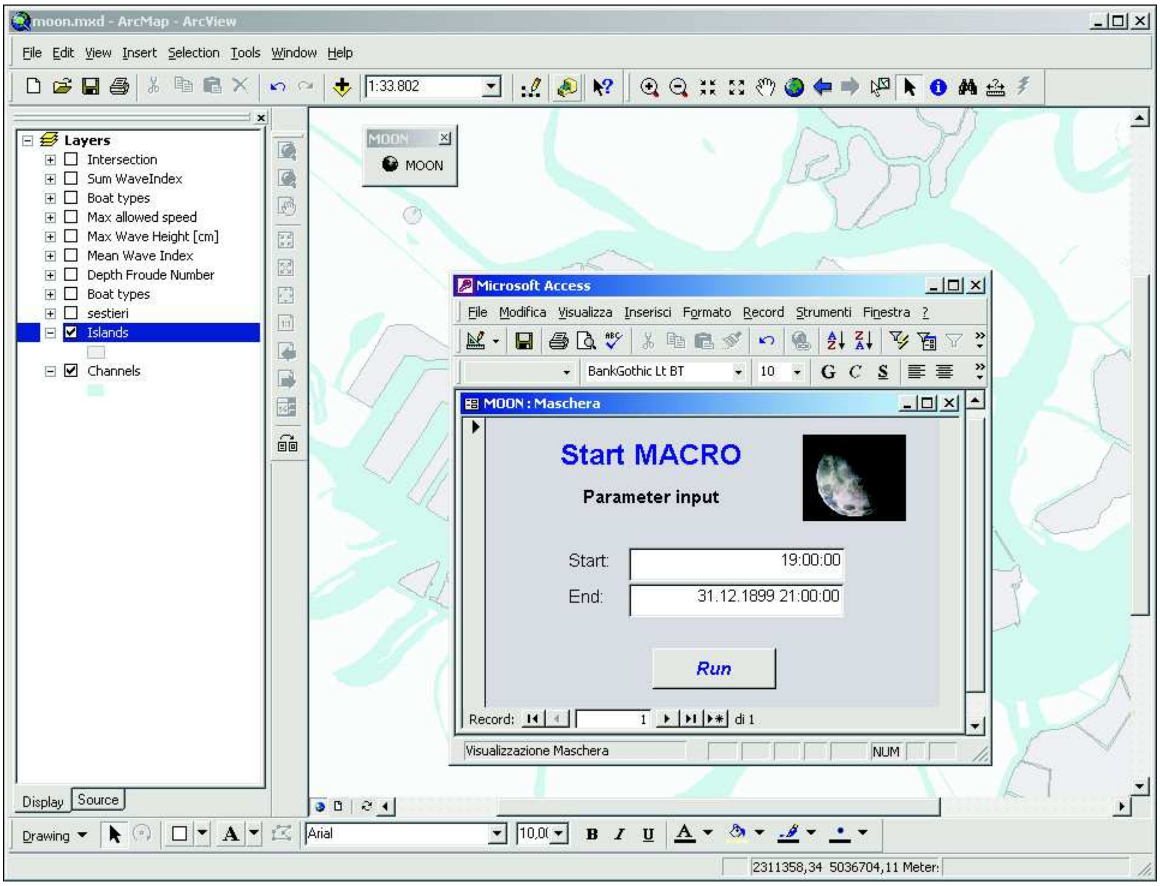


Figure 5.4: Created button and mask

To be later able to join the traffic network (grafo_segmenti) with the results of a query, a database connection in ArcCatalog with the database Simulatore.mdb has to be made (figure 5.5).

The layer grafo_segmenti is loaded from the feature dataset 'Venezia' and got connected over a join (figure 5.6) with the necessary queries or tables. Now the results from the calculation in ACCESS can be visualised.

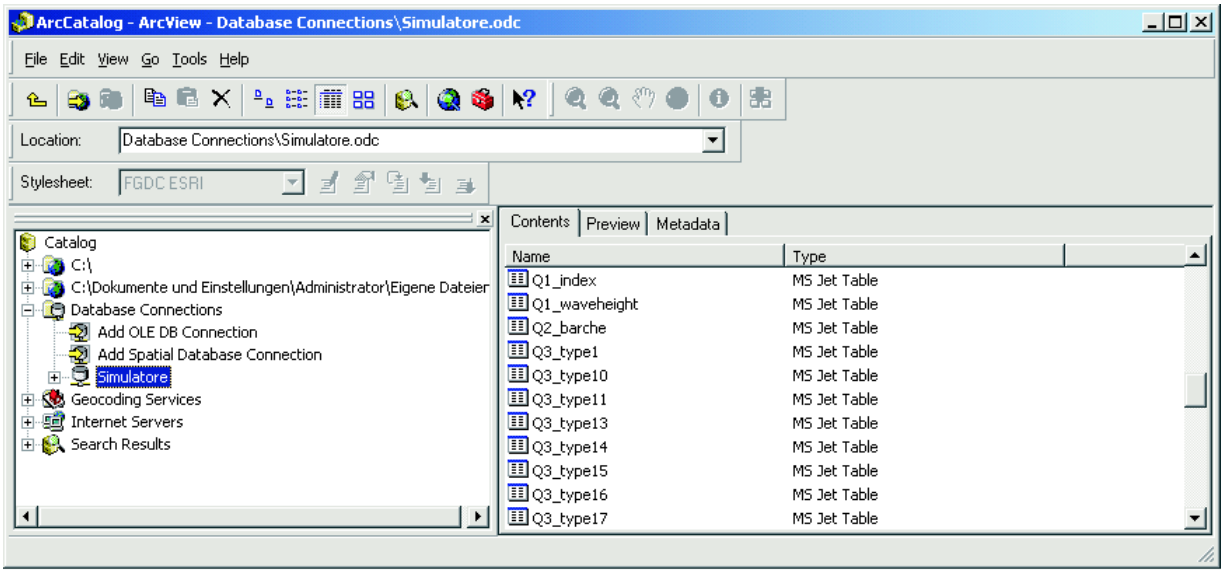


Figure 5.5: Database connection in ArcCataloge

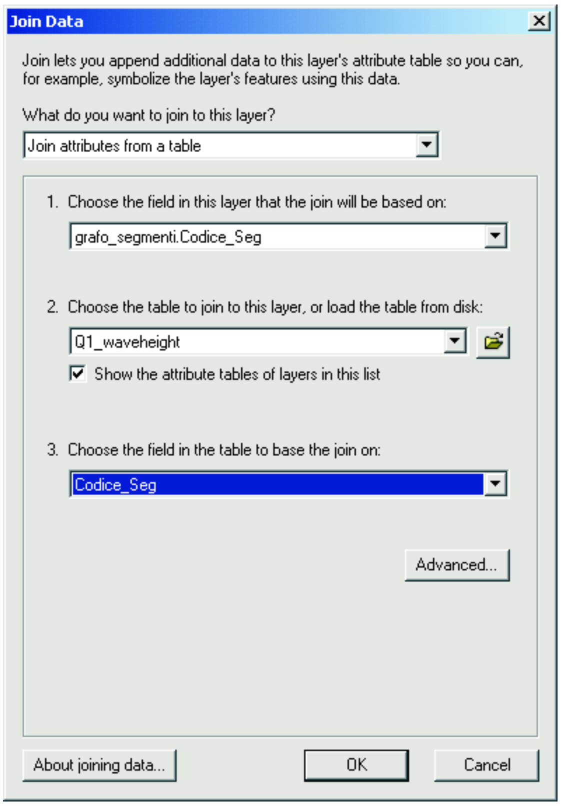


Figure 5.6: Join of layer grafo_segmenti with a query

5.3 Results

The results concerning the maximum wave heights have to be evaluated carefully. As it was mentioned before there are many influencing factors which have been neglected in the calculation that one can assume of which the results provide realistic values. An interpretation (qualitative evaluation) will be made in order to provide an indication of the quality of the results that are generated.

Residual Resistance Like mentioned in section 2.3.1 an additional possibility to show when a certain boat passes a critical speed for the wave generation is the residual resistance. It is depending on boat characteristics (displacement, ship length and speed). The limit curve, which was modified for Venice, defined by the "Technical Commission for the Study of the Moto Ondoso" has to be compared with the curves of the residual resistance for every boat type. The values for a speed until 20 km/h were controlled, which is theoretically the maximum allowed speed (figure 4.5).
Just three boat types of the existent list can come in critical range regarding the residual resistance. Figure 5.7 shows the three boat types together with the limit curve. The 'Topo grande' reach the limit with a speed of 13 km/h, the 'Taxi' at a speed of 16 km/h and the 'Granturismo' at 15 km/h.

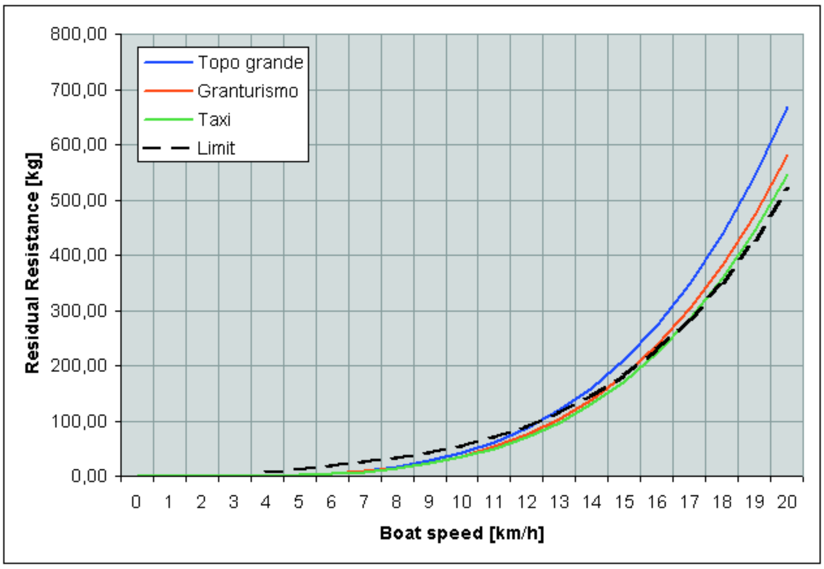


Figure 5.7: Residual resistance for three boat types and limit curve

Figure 5.8 shows the segments of the traffic network in which the limit for the residual resistance of these three boat types were reached or exceeded.

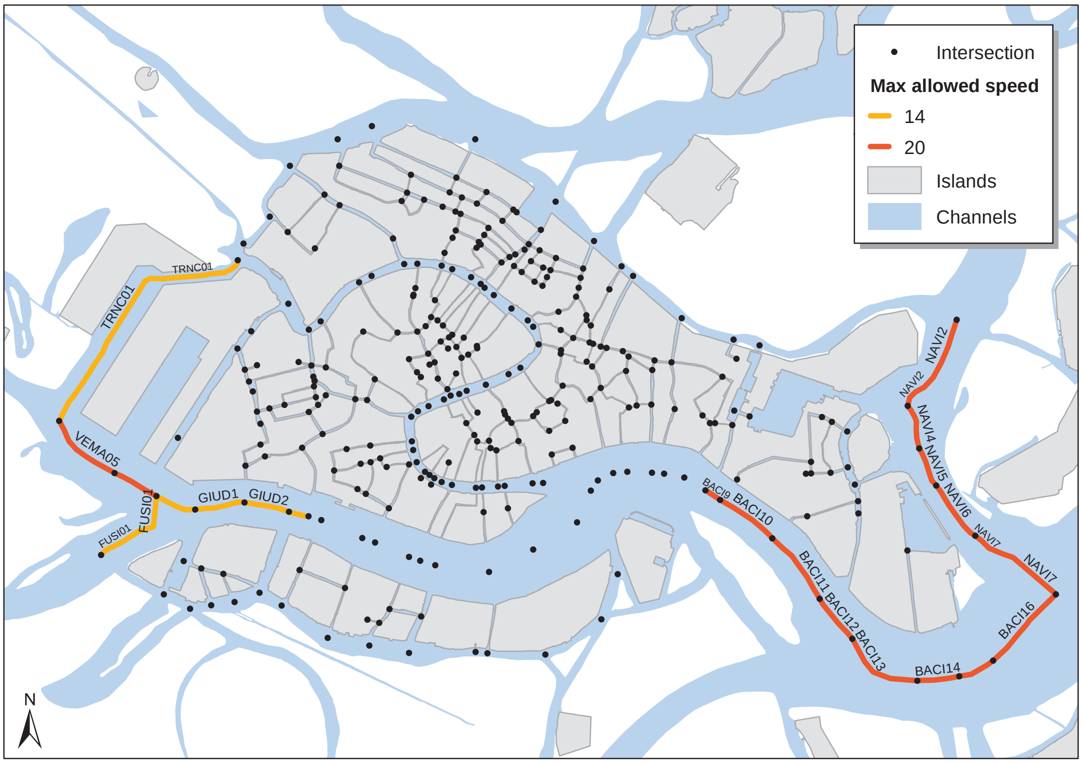


Figure 5.8: Channel sections where the limit curve of the residual resistance is exceeded

Depth Froude Number The depth Froude number indicates the characteristic of the wave pattern around vessels moving in shallow water. It is depending on ship speed and water depth and reaches a transcritical range with the values 0,9-1,1 (section 2.1.3). Using the maximum allowed speed and the water depth of the channels the non-dimensional number was calculated and visualised in GIS, as shown in figure 5.9. As you can see the critical level cannot be reached when the boats keep the speed limit.

Wave index and wave height After connecting the layer grafo_segmenti over a join with the query Q1_waveheight the following figure 5.10 was created for the time interval from 5:00-22:00. It shows the maximum wave height in centimetre that was produced in the channels during the five simulated days. The results of the wave height should be carefully valued, but in general the values are quite low and should be compared with measured data. But the quality of the results seem to be realistic: in wider channels the highest waves are produced among other things in consequence of the higher speed limits (figure 4.5). The internal channels have all a low maximum wave height because there the speed limit is just 5 km/h.

Figure 5.11 represents the average diurnal sum of $\frac{g \cdot H}{V^2}$ (wave index) and gives information where during one day the intensity of the wave generation is higher or lower. Among other

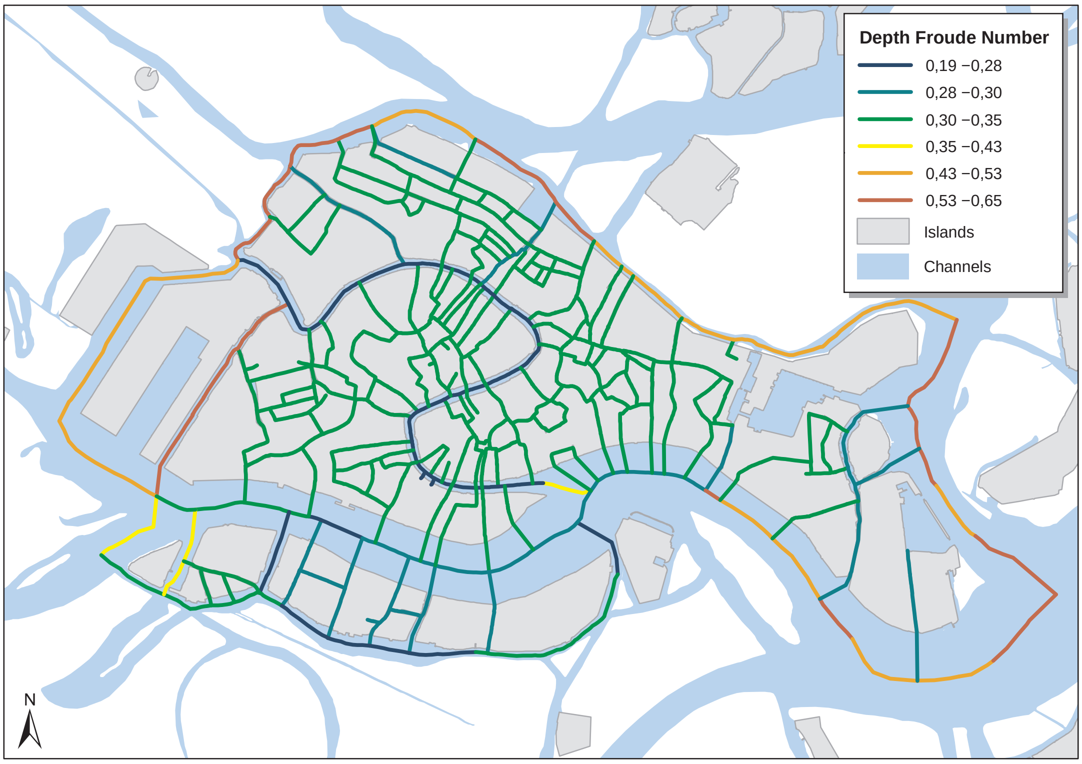


Figure 5.9: Deep Froude numbers of the channel network

things the result is depending on the traffic volumes in the channel. Due to the higher values in general (5.10) and a higher traffic volume the channels have higher values.

To know which part the individual boat types have on the wave generation, a join with the table tab_barche_stat was created. Figure 5.12 give a general over view of the hole historical centre. No detailed analysis will be given but in general it can be noticed that especially two boat types are dominant in their percentage on the sum: the 'Taxi' and the 'Topo medio'.

With the combination of both the portions of the boat types and the wave index sum better analysis can be done. Therefore smaller cuttings are shown in the next figures (5.13, 5.14, 5.15, 5.16, 5.17, 5.18, 5.19, 5.20). In these images different time intervals are represented. Therefore the button MOON was used and the starting and ending time was entered in the mask. After the refresh the map got updated. This method represents a easy and fast way to create maps of different time intervals.

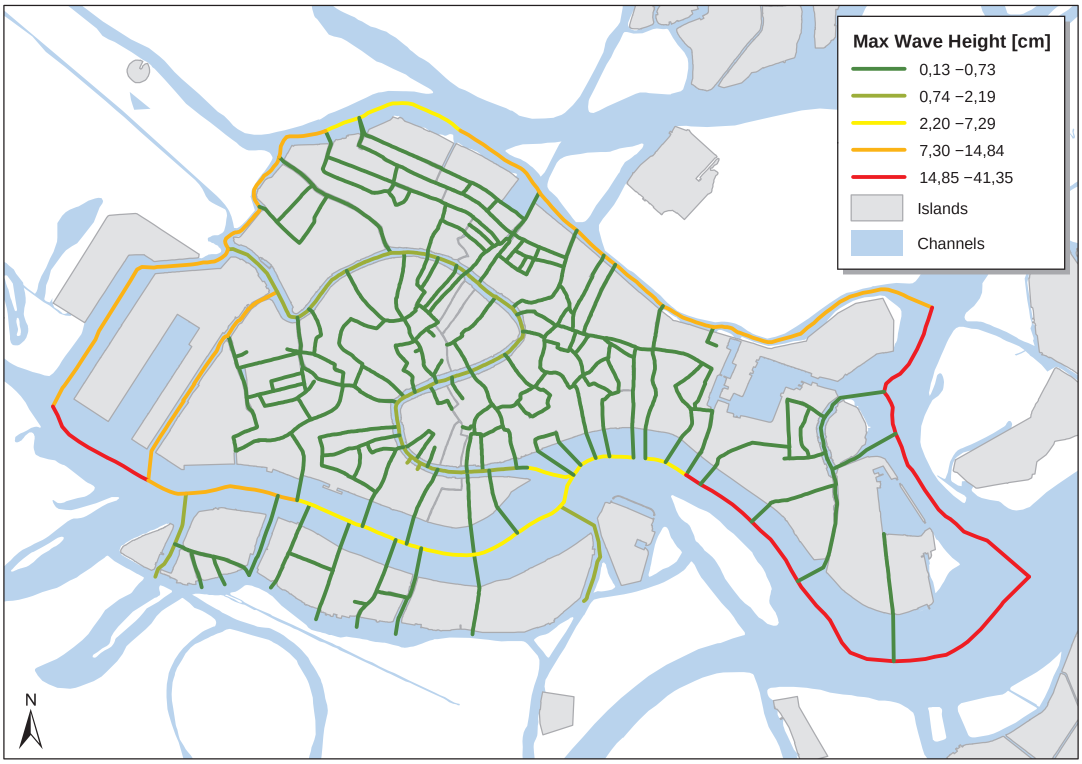


Figure 5.10: Maximum occurred wave heights over one day

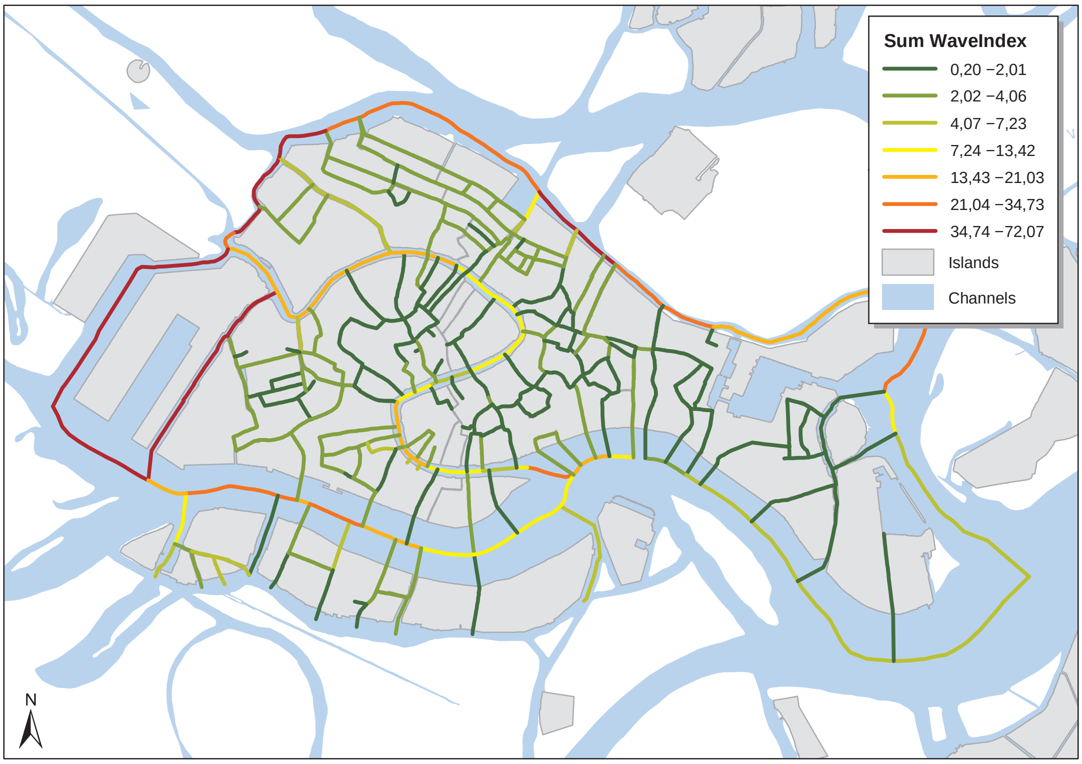


Figure 5.11: Average diurnal sum of the wave index $\frac{g \cdot H}{V^2}$

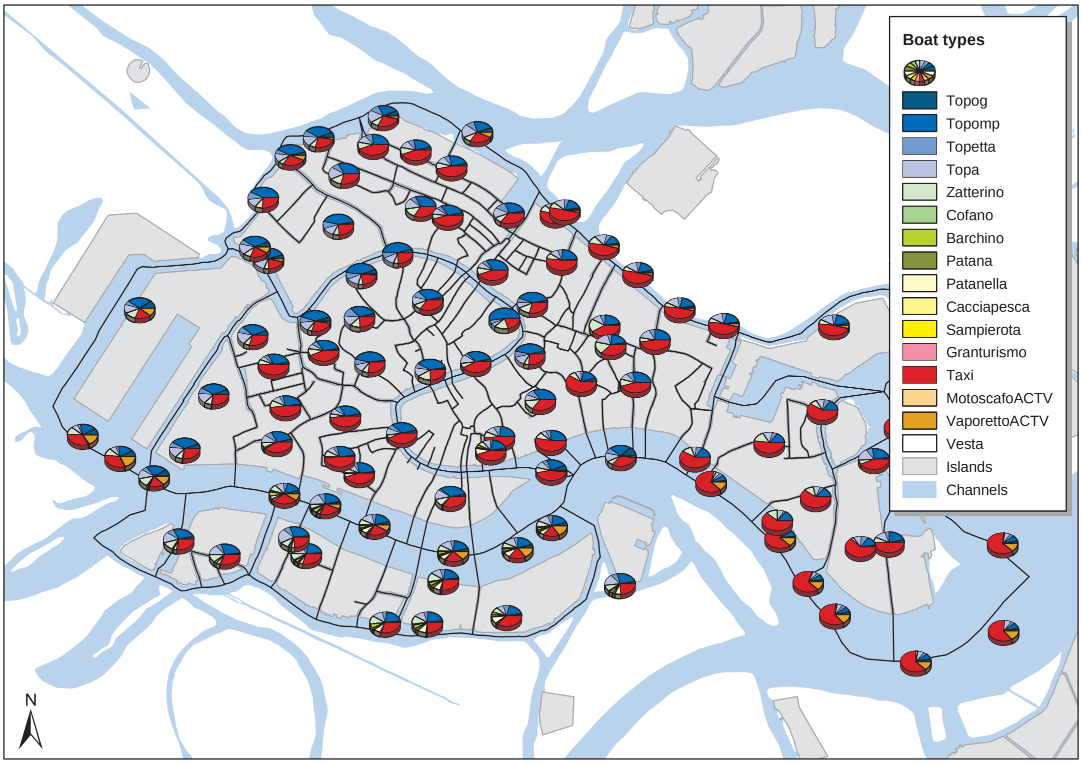


Figure 5.12: Percentages of the various boat types on the wave generation

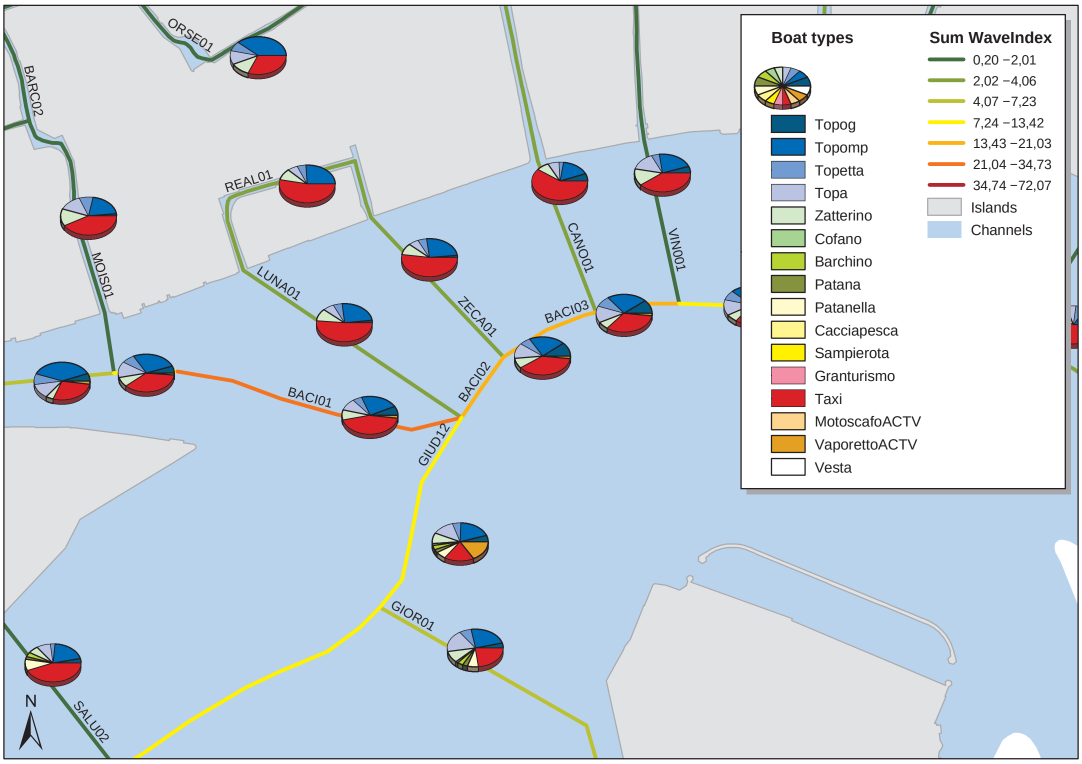


Figure 5.13: Parts of the boat types and sum of the wave index: 5:00-22:00

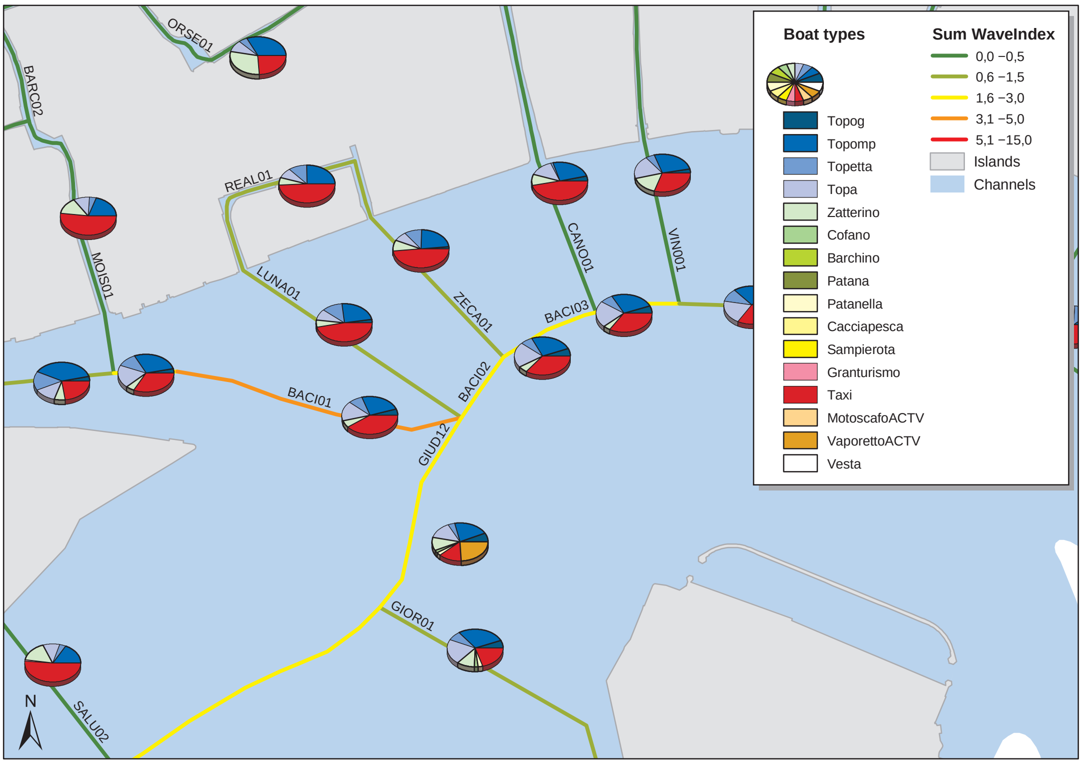


Figure 5.14: Parts of the boat types and sum of the wave index: 7:00-9:00

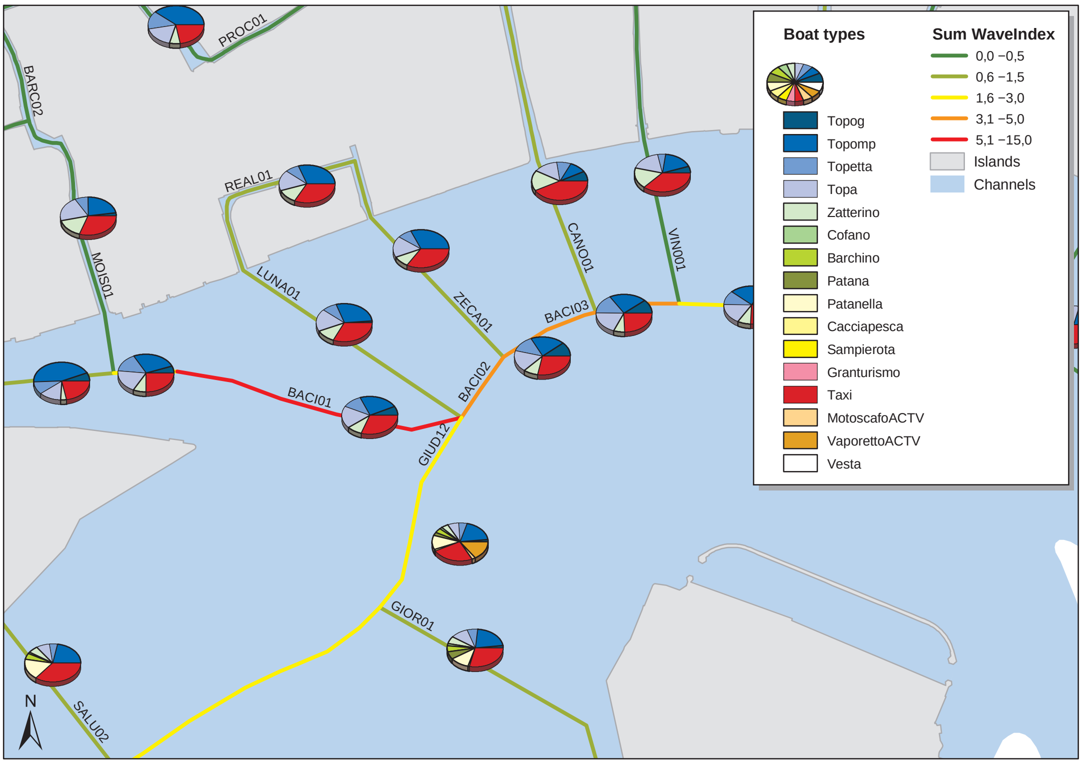


Figure 5.15: Parts of the boat types and sum of the wave index: 9:00-11:00

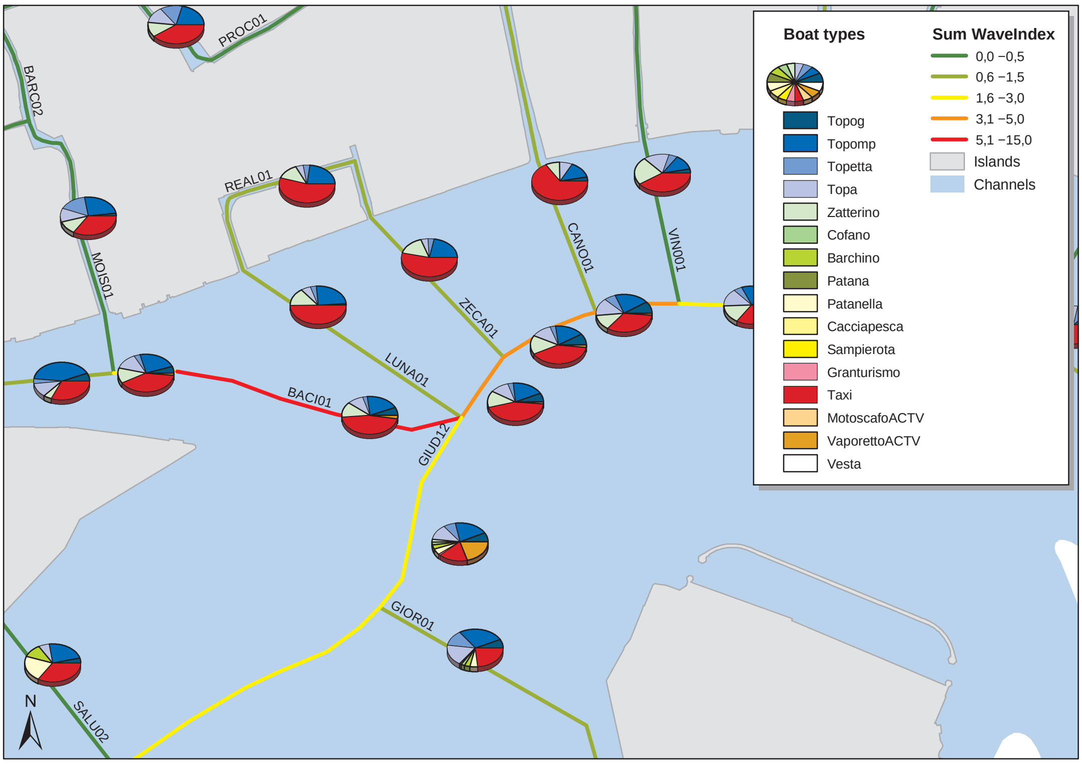


Figure 5.16: Parts of the boat types and sum of the wave index: 11:00-13:00

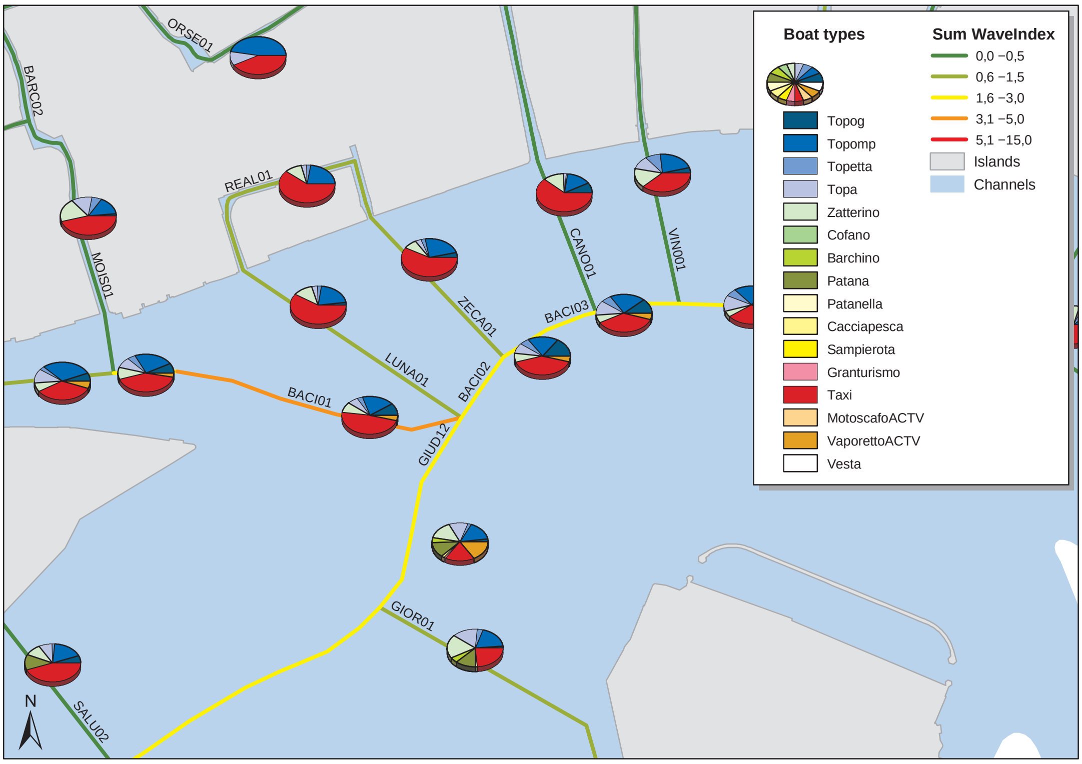


Figure 5.17: Parts of the boat types and sum of the wave index: 13:00-15:00

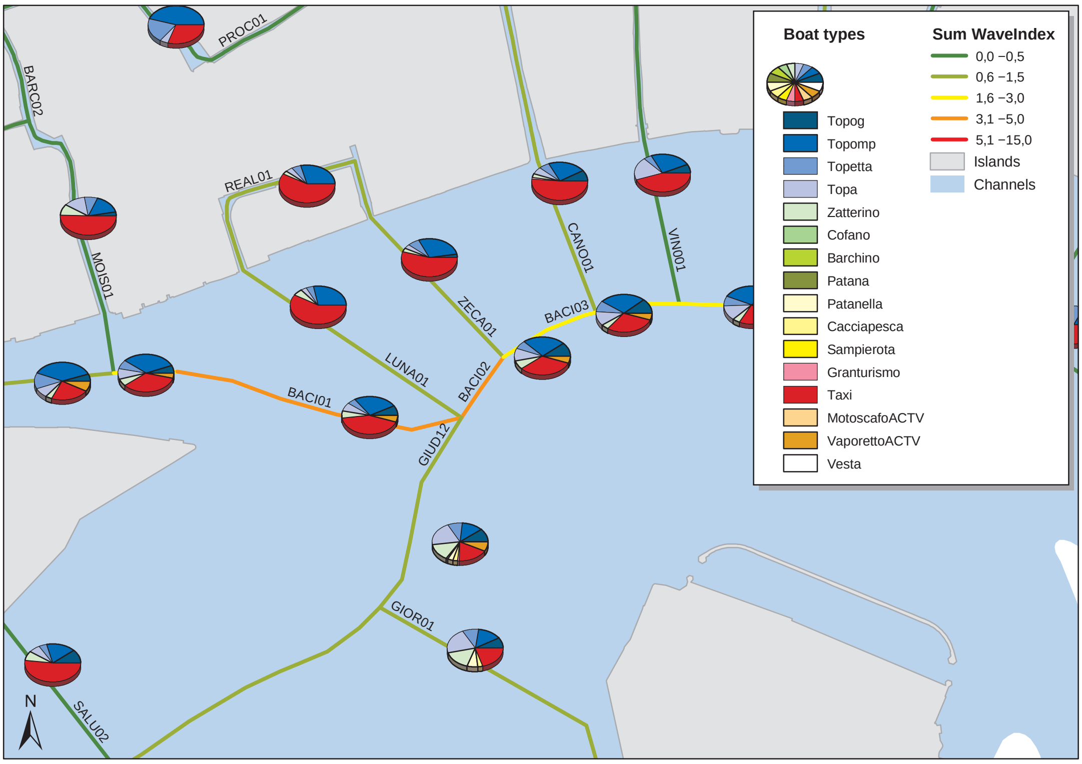


Figure 5.18: Parts of the boat types and sum of the wave index: 15:00-17:00

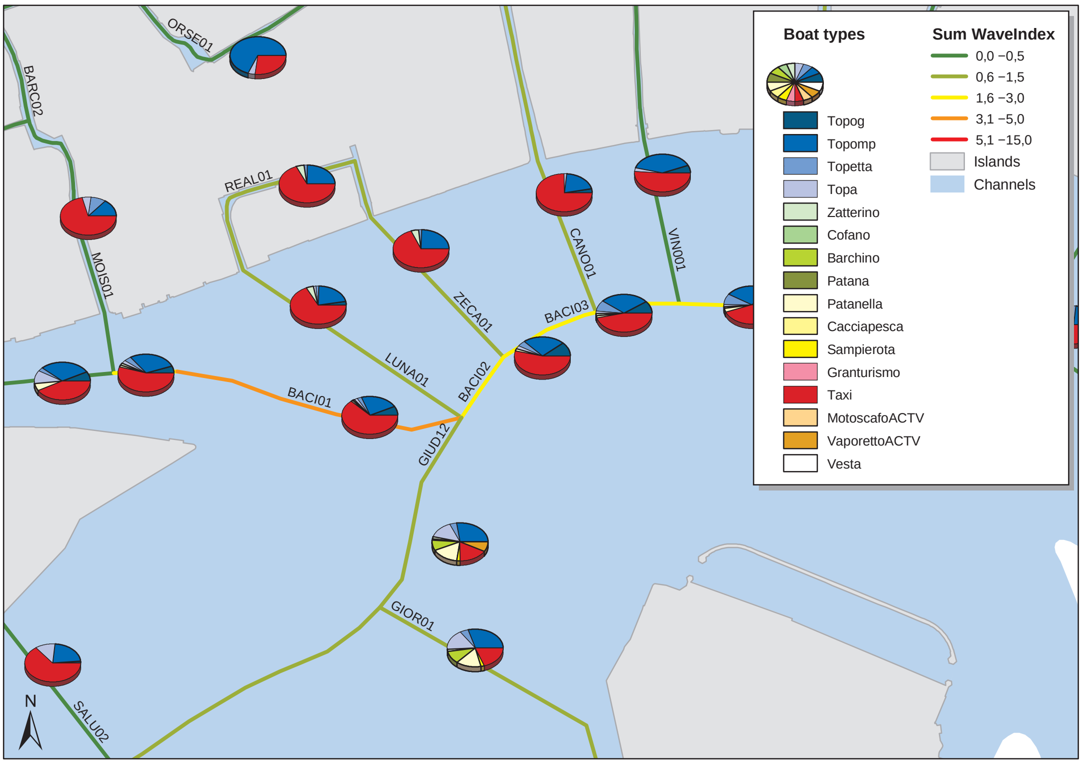


Figure 5.19: Parts of the boat types and sum of the wave index: 17:00-19:00

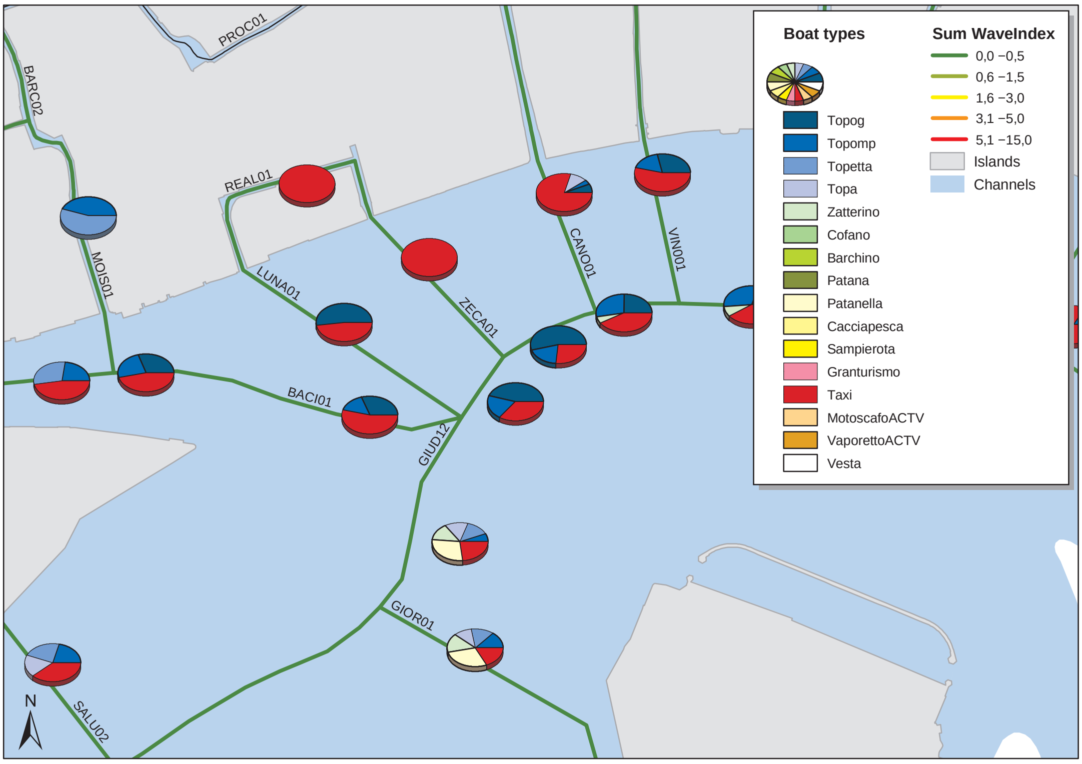


Figure 5.20: Parts of the boat types and sum of the wave index: 19:00-21:00

Chapter 6

Conclusion

This work confronted the necessity to create a decision support system for the evaluation of the 'moto ondoso' in the historical centre of Venice. One aim was to make clear the difficulties of this undertaking. Not only the inclusion of many important informations but also the existence of a formula for the calculation represent obstacles.
The application MOON can just be seen as a first step toward the modulation of the 'moto ondoso'. There is too much important information missing and the traffic network as well as the boat types are too simplified. Models of tidal currents, engine turbulences and wave evolution should also be included.
The monitoring of the water traffic, in the last years, has quantified the traffic volume in the most critical points and also estimated the growth rate of the boats. For planning the use of the navigable network in the future, there are ulterior studies and monitoring necessary to quantify the energy unloaded from the traffic in the waters of the channels.

GIS opens up a wide potential for managing data through the components space, time and attribute. Unfortunately time is currently poorly integrated into GIS software. Basic concepts of a temporal GIS such as temporal data types, possible temporal changes, temporal modelling were illustrated in this work. The project MANTA, including a traffic volume simulator, a historical database and dynamic visualisation was introduced. And it was ascertained that with the historical database and the implemented tool for dynamic visualisation, this demonstrates a first step toward spatio-temporal GIS. But it is missing one important general part: a function for analysing changing patterns over time.
The presented application MOON, based on the data of the project MANTA, offers a easy and fast visualisation method of a wanted time interval, using a macro implemented in ACCESS.
These examples demonstrate that GIS users are still left on their own in handling spatio-temporal data and it can be concluded that the use of temporal GIS instead of

conventional GIS will be ineluctable in the near future.

Bibliography

Brighenti, A., Di Bussolo, R., Fiorin, F., Pavon, M., and Sebastiani, G. (2003). *Il manuale del lagunante - Guida pratica per l'operatore professionale ed il diportista*. Settore Trasporti e Mobilità, Provincia di Venezia, Venice. Available at `www.comune.venezia.it/motondoso/pdf/manuale\_navigante.pdf`.

Consorzio Venezia Ricerche (2002). Studio per la definizione di metodi e strumenti necessari alla verifica dell'attitudine alla navigazione nella Laguna di Venezia. Available at `http://www.provincia.venezia.it/traspo/naviglag/studio/Sommario.html`.

Croad, R. and Parnell, K. (2002). *Proposed controls on shipping activity in the Marlborough Sounds: A review under Section 32 of the Resource Management Act*. Marlborough District Council.

Freelan, S. (2003). Developing a Quasi-Temporal GIS for Archival Map Data. Presented at the 2003 ESRI User Conference, available at `http://www.ac.wwu.edu/~stefan/tgis.htm`.

Halls, P. and Miller, P. (1996). Of todes and worms: An Experiment in bringing Time to ArcInfo. In *Proceedings of the 11th ESRI European Conference*, London.

Havelock, T. (1908). The propagation of groups of waves in dispersive media with application to waves on water produced by a travelling disturbance. In *Proceedings Royal Society*, pages 398–430, London.

Heo, J. and Adams, T. (1997). Temporal Database Models for GIS. In *URISA Annual Conference Proceedings*, Toronto.

Huesig, A., Linke, T., and Zimmermann, C. (1999). Hydraulic and environmental impacts of high speed cargo ships on inland waterways. In *Proceedings of the 1st European Inland Waterway Navigation Conference*.

Jiang, T., Henn, R., and Sharma, S. (2002). Wash Waves Generated by Ships Moving on Fairways of Varying Topography - Experimental and Numerical Results. Available at `http://www.vbd.uni-duisburg.de/publications/webs/m290/m290.htm`.

Kainz, W. (2004). Geographic Information Science. Universität Wien, Institut für Geographie und Regionalforschung. Skriptum.

Kriebel, D. (2003). Development of a unified description of ship-generated waves. Available at `http://ourworld.compuserve.com/homepages/jgleuel/ip-zit.htm`.

Langran, G. (1992a). State, events and evidence: The principle entities of a temporal GIS. In *Proceedings of GIS/LIS*, pages 416–425.

Langran, G. (1992b). *Time in Geographic Information Systems*. Taylor & Francis.

Langran, G. and Chrisman, N. (1988). A framework for Temporal GIS. *Cartographica*, 25(3):1–14.

Libby, M. (2003). *Fast Ferry Operations and Issues*. Maine Dept. of Transportation. Available at `http://www.maine.gov/mdot/transportation-research/pdf/`.

Liou, J. (1999). *Temporal Support for Land Information Systems in Object-Oriented Modeling*. PhD thesis, University of Stockholm.

Macfarlane, G. and Renilson, M. (1999). Wave Wake - A Rational Method for Assessment. In *Royal Institution of Naval Architects International Conference on Coastal Ships and Inland Waterways*, London. Available at `http://www.amc.edu.au/mte/shc/publications/pdf/GJM_RINA_Feb99.pdf`.

Malczewski, J. (1999). *GIS and Multicriteria Decision Analysis*. John Wiley and Sons, New York.

Maritime and Coastguard Agency (2001). A Physical Study of Fast Ferry Wash Characteristics in Shallow Water. *Maritime and Coastguard Agency, Res. Proj. 457*. Available at `http://www.qub.ac.uk/waves/fastferry/reference/MCA457.pdf`.

Nadi, S. and Delavar, M. (2003). Spatio-Temporal Modeling of Dynamic Phenomena in GIS. In *Proceedings of ScanGIS*, pages 215–225.

Peuquet, D. (1994). It is about time: A conceptual framework for the representation of temporal dynamics in GISs. *Annals of the Association of American Geographers*, 84:441–461.

Peuquet, D. and Duan, N. (1995). An event-based spatio-temporal data model (ESTDM) for temporal analysis of geographical data. *International Journal of Geographic Information System*, 9(1):7–24.

Raza, A. (2001). *Object-Oriented Temporal GIS for Urban Applications*. PhD thesis, University of Twente.

Shaw, S. (2000). Moving Toward Spatiotemporal GIS for Transportation Applications. In *Proceedings of the 20th ESRI User Conference*. Available at `http://www.esri.com/library/userconf/archive.html`.

Single, M. (2001). *Wake Wash Measurements in Tory Channel, Marlborough Sounds*. Land and Water Studies International Ltd, New Zealand. Available at `www.marlborough.govt.nz/assets/TranzSpeedExemptionApplnPart34\&5-nmo.pdf`.

Snodgrass, R. (1992). Temporal databases. In Frank, A., Campari, I., and Formentini, U., editors, *Theories and Methods of Spatio-Temporal Reasoning in Geographic Space*, pages 22–64, Berlin. Springer-Verlag.

Sorensen, R. (1997). *Prediction of Vessel-Generated Waves with Reference to Vessels Common to the Upper Mississippi River System*. US Army Corps of Engineers. Illinois Waterway System Navigation Study, ENV Report 4.

Wesseling, C., Karssenberg, D., Burrough, P., and Van Deursen, W. (1996). Integrated dynamic environmental models in GIS: The development of a Dynamic Modelling language. *Transactions in GIS*, 1:40–48.

Whittaker, T. and Elsäßer, B. (2000). Coping with the wash: The nature of wash waves produced by fast ferries. Available at `http://www.raeng.org.uk/news/publications/ingenia/issue11/Ingenia%2011%20Whittaker.pdf`. Queen's University, Belfast.

Worboys, M. (1992). A model for spatio-temporal information. In *Proceedings of the 5th International Symposium on Spatial Data Handling*, pages 602–611, South Carolina.

Worboys, M. (1994). Object-oriented approaches to geo-referenced information. *International Journal of Geographical Information Systems*, 8:385–399.

Yuan, M. (1994). Wildfire conceptual modeling for building spatio-temporal GIS. In *Proceedings of GIS/LIS*, pages 860–869.

Yuan, M. (1996). Temporal GIS and spatio-temporal modeling. In *Integrating GIS and environment modeling*.

Zhao, F. (1997). Transportation applications of temporal GIS. In *ESRI Conference Proceedings*, San Diego. Available at `http://www.esri.com/library/userconf/proc97/proc97/to450/pap427/p427.htm`.

Zhong and Dingqiang (1996). Developing Temporal Land Information Systems in Arc/Info. In *Proceedings of GIS/LIS*, pages 1233–1250, Bethesda. American Congress on Surveyng and Mapping.

Zotti, I. (2002). Definizioni di metodi e strumenti necessari alla verifica dell'attitudine alla navigazione nella laguna di Venezia. Available at http://www.provincia.venezia.it/traspo/naviglag/studio/Sommario.html.

Appendix A

Abbriviations

CVR	Consorzio Venezia Ricerche
DBMS	Database Management System
ESTDM	Event-oriented Spatio-temporal Data Model
GIS	Geographic Information System
MANTA	Modello d'ANalisi del Traffico Acqueo (Model for the Analysis of the Water Traffic)
MOON	MOto ONdoso

Appendix B

Symbols

B	vessel beam
C_B	block coefficient
d	water depth below the still water level
F_d	depth Froude number
F_L	length Froude number
g	acceleration of gravitiy
H	wave height
H_m	maximum wave height
K_n	factor changing with hull form
L_e	hull entrance length
L_s	ship length
L_{wl}	ship length at water
R_R	Residual Resistance
T	vessel draft
V	vessel speed
y	distance from sailing line
α	coefficient in equation
β	coefficient in equation
Θ	angle between sailing line and wave propagation direction

Erklärung:

Ich versichere, diese Master Thesis ohne fremde Hilfe und ohne Verwendung anderer als der angeführten Quellen angefertigt zu haben, und dass die Arbeit in gleicher oder ähnlicher Form noch keiner anderen Prüfungsbehörde vorgelegen wurde. Alle Ausführungen der Arbeit die wörtlich oder sinngemäß übernommen wurden sind entsprechend gekennzeichnet.

Venezia-Marghera, 30.08.2004