DEVELOPMENT OF THE WET INFRASTUCTURE OF THE PORT OF BAHIA BLANCA IN ARGENTINA

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ABSTRACT

This paper is focused on the development of the port layout considering the ship manoeuvring, mooring and "passing-ships" simulations followed by the traffic flow simulations, where the initial ship operation studies provide the necessary boundary conditions for a traffic flow simulation study.

The main object of the paper is to show the importance of combination of high level simulation techniques (**ship manoeuvring, ship moorings, passing ships interaction, traffic flow simulation study**) to monitor the performance of the port, taking into account environmental conditions as well as the provided facilities, to come to a balanced masterplan of the Port of Bahia Blanca.

Based on safety criteria, the output of manoeuvring simulation study provides traffic rules and manoeuvring strategies, which in turn are used as input for the traffic flow simulation model to determine the capacity of the infrastructure.

1. DESCRIPTION, CONFIGURATION OF THE PORT COMPLEX, PORT THROUGHPUT, TRAFFIC FORECAST AND ENVIRONMENTAL CONDITIONS

Bahia Blanca estuary has an approximate length of 100 km and a surface of 2300 km^2. The estuary is composed of a series of channels, oriented NW-SE, wide tide flatlands and islands. The navigation channel which gives access to the port has significant complications due to its length (98km), its route (Outer Channel, Paso del Toro, Inner channel) and its width (190m minimum wide); all of it combined with intense tidal currents (up to 2 knots) and strong winds cross to the channel (up to 20-25 knots).

This complex navigation channel, mostly one way, is subject to many and complex traffic rules, therefore a highly renewed VTS service controls all the inbound and outbound traffic of Bahia Blanca port.

All of this complex navigation rules are highly dependent on the recent traffic of LNG carriers towards MEGA terminal. This upgraded terminal came into service in June 2008 introducing a new activity for the port of Bahia Blanca, but also additional requirements derived from the type of cargo and the very large size of vessels. This new market required a deep analysis of all the manoeuvring areas and navigation channel in order to take the actions required to ensure the safe access of these LNG carriers.

The new Mega terminal has been accommodating the new LNG traffic and it is placed on the inner navigation channel of the port. Therefore, the permanently moored FSRU (Floating, Storage and Regasification Unit) is continuously exposed to the influence of the tankers that sail towards Puerto Galvan. This effect is enhanced when a LNG carrier is moored side by side to the FSRU because part of the inner channel of the port is occupied by the LNG supply vessel, thus limiting the access to the inner part of Bahia Blanca, Puerto Galvan.

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Figures 1 and 2 show the Bahia Blanca estuary and Bahía Blanca port complex.

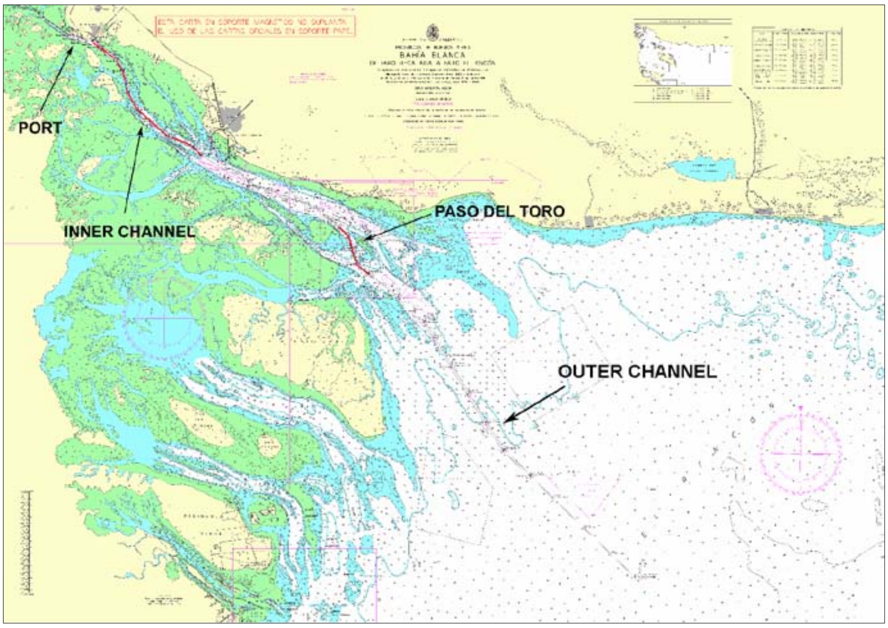

Figure 1. Bahía Blanca estuary

Figure 2. Bahía Blanca port (Puerto Galvan and Ingeniero White)

The traffic increase during last years, together with the traffic forecast which foresees an increase in the traffic volume has accelerated the improvements and optimization of the navigation channel and the port area in order to accommodate the increased traffic linked to new terminals under development.

It is critical to find the optimum compromise between economical costs and navigation channel improvements, aimed at increasing productivity and reducing waiting times.

In order to fulfill these objectives several simulation models have been used to determine the safe access conditions to the port. The simulation methods applied were:

1. manoeuvring simulation
    a) "fast-time" manoeuvre simulation (SHIPMA)
    b) real-time manoeuvre simulation (MERMAID500)
2. moored vessels simulations (SHIP-MOORINGS)
3. "passing-ships" simulations (DELPASS)

The results of these tools are used as input for the traffic flow simulation models, thus the bottlenecks of the port system can be identified, actions over those can be taken and therefore an optimization of the required improvements, to reduce or eliminate the initial bottlenecks, can be done.

2. SHIP MANOEUVRING, MOORINGS AND "PASSING-SHIPS" SIMULATION STUDIES

The first phase of the simulations covered the manoeuvring and mooring simulations. The objective of this phase was to analyze and assess the navigation and turning areas, towing requirements and the combination of speed-distance of vessels in the inner navigation channel of the port.

These analyses allow the update and improvement of the traffic rules of Bahia Blanca port that serve as input for the traffic flow simulation model.

The objectives of this phase of studies were:

1. Evaluation of the navigation and turning areas, considering both the depth and geometry of the general layout of the port
2. Evaluation of the operation limits for inbound and outbound manoeuvres
3. Analysis of manoeuvring strategies and tug assistance
4. Analysis of emergencies as a basis for the elaboration of contingency plans
5. Analysis of the safe sailing distance and speed in the inner channel of the port due to "passing-ships" effect
6. Training of Captains and Pilots

2.1 Manoeuvring studies

Manoeuvring studies were performed first. A deep analysis of the historical data of metocean conditions (wind, waves and current) was performed. These manoeuvring studies were performed using two different simulation models: a "fast-time" simulation model and a real-time bridge simulator.

2.1.1 Manoeuvring simulations

In order to perform the simulations in the real-time bridge simulator a virtual 3D model was built, including all the main sections of the navigation channel and the port.

These manoeuvre simulations were carried out using Siport21's **real-time manoeuvring simulator**, developed by MARIN-MSCN (The Netherlands). The simulation model included the following items:

1. General arrangement:

    Information on the topography and bathymetry of the interest area was analyzed. The required visual 3D model was built to show the topography of the environment during the real-time simulation. Existing port structures (quays, jetties, etc), buildings and loading/unloading equipment and existing aids to navigation (buoys) were also included. The following figure shows part of the visual model of Bahia Blanca port developed for the real-time simulations:

Figure 3. Bahia Blanca manoeuvring simulation model

2. Metocean conditions:

   Detailed information on the physical and meteorological conditions of the area was analyzed. In particular: tide, current fields, wave fields with the distribution of wave heights and local directions for the main sectors, wind fields with the distribution of wind speed and local direction.

3. Vessels and tugs

   Hydrodynamic models of the target vessels that adequately reproduce their behavior when sailing or manoeuvring in deep or shallow water, and subject to the action of currents, waves and wind. The required tugs were also incorporated in the simulations to perform some of the manoeuvres, taking into account their main dimensions, power, bollard pull and the characteristics of the propulsion/steering system.

The access and departure manoeuvres were reproduced using Siport21's real-time bridge simulator. This system reproduces the behavior of a specific vessel during the execution of the access or departure manoeuvres in the port, subject to the action of external agents (wind, currents, waves, limited depth, bank suction, etc.) and assisted by tugs if required.

A Captain or Pilot using the system operates in a bridge mock-up with real instruments, ECDIS and a radar screen. The motions of the ship are seen on a 260º wide screen 12 meters diameter. Sounds (engine, wind, horns) are also perceived. (See Figure 4)

Figure 4. Siport21's real-time manoeuvring simulator

The manoeuvring mathematical model is highly accurate and handles 6 degrees of freedom models, with horizontal and vertical motions. Different ship types and sizes can be easily simulated, considering various propulsion and steering systems. Approach manoeuvres, as well as berthing and de-berthing may be analyzed, together with anchoring and mooring manoeuvres. Tug operation is very detailed, and either conventional or special units (tractor, VWT, ASD, etc.) can be included.

Pre-processing tools are available for the precise generation of simulation models of port areas in a very flexible way. Post-processing of the simulation results is also possible, with plotting and statistical analysis applications ready for the evaluation of Port Design and Nautical Operations.

The **mathematical model** in the simulation system calculates the forces and moments acting upon the ship, both hydrodynamic, propulsion and steering, and those from external agents, and it solves the equations of motion in 6 degrees of freedom.

The mathematical manoeuvring model is able to reproduce the ship's behaviour under the action of the following forces: hydrodynamic forces on the hull, propulsion, rudder forces, bow/stern thruster forces, variable depth, wave, wind and current forces, bank suction effects, tug forces.

The manoeuvring characteristics are compiled in a series of hydrodynamic coefficients (proportionality constants between forces, movements and its derivatives). The hydrodynamic coefficients are usually obtained from scale model tests. Their validity is then contrasted by comparing the behavior of the ship model with the results of real ship standard manoeuvrability tests, both in deep and shallow waters:

1. Speed - Engine rate curves
2. Turning manoeuvre
3. Zig-Zag manoeuvre
4. Stopping manoeuvre
5. Acceleration manoeuvre
6. Spiral manoeuvre

Vessel definition is completed with files including the main dimensions, propulsion characteristics, auxiliary manoeuvring equipment, wind coefficients (forces and moments for different incidence angles), wave coefficients (forces, moments and motions for different incidence angles and wave periods), current coefficients (forces and moments for different incidence angles) and bank suction coefficients.

Human factor is involved in the manoeuvring process, so that most accurate results are obtained in a realistic working environment. Therefore, this tool is specially focused to complex manoeuvres (restricted areas, severe weather conditions, complex ships, tug activity, etc.) where human decision making is most relevant.

In following steps of the project night simulations were also performed in order to assess the access and departure of large LNG carriers calling MEGA Terminal at all times, thus the traffic flow and the port efficiency can be increased.

2.1.2 Emergency simulations

Simulation program covered both normal conditions (access simulations with two different turning areas, and departure simulations) and several emergency situations.

Manoeuvres in normal conditions were performed in the real-time simulation model while several emergency scenarios were analyzed using “fast-time” simulation software.

The first phase of the study was developed applying the **fast-time ship manoeuvring program SHIPMA**, developed by Delft Hydraulics-MARIN (The Netherlands). This program computes the track and course angle of the vessel, taking into account the influences of wind, waves, currents, shallow water and bank suction. Rudder, engine and tug control is effectuated by a track-keeping autopilot that anticipates deviations from desired track and changes in currents. Control algorithms are also available for bow and stern thrusters

The emergency manoeuvres which were considered in the study were the following:

1. Blackout at the channel
2. Emergency stop at the channel
3. Blackout at the inner part of the channel
4. Rudder blockage
5. Emergency exits
    a) Extreme wind
    b) Extreme current
    c) Limited assistance by tugs

2.1.3 Simulation results

A total of 85 different scenarios were covered and 108 simulations were performed, which means more than 60 hours of simulation.

In a first phase Puerto Galvan turning basin was established for the turning of the LNG carriers when accessing MEGA Terminal. After several simulation sessions with local Pilots, the turning basin for the LNG carriers was established at Ingeniero White Turning Basin, which is wider and deeper, even if it implies sailing backwards to the FSRU jetty. This modification allowed more continuous and safe operations.

The main conclusions derived from the study were the following:

1. The available manoeuvring area in the port was considered sufficient, taking into account the evaluation of meteorological limits and tug use. The channel between Rada A and the turning area in Puerto Galvan is wide enough to permit the passage of the vessels considered including their respective tug formation.
2. The stopping distance, approximately between buoy number 3 and the West end of the turning area, is considered sufficient under the conditions analyzed, as the ships arrive to the stopping and turning area under control by their own means plus tug assistance.
3. The turning area is considered wide enough to turn around and change course towards the jetty, as far as the manoeuvring strategies are correctly applied. This area allows turning either to port or to starboard, depending on the wind direction and any other circumstances considered by the Pilots.
4. The berthing manoeuvre is carried out with the vessel under control, and the impact velocity of the vessel over the fenders can be controlled with tug assistance and manoeuvring thrusters.
5. The basic tug formation in the final phase of the approach manoeuvres to port was 4 ASD units with a bollard pull of up to 50 tons each. For most of the manoeuvres, two tugs were connected at the bow and the stern and the other two at the starboard shoulders.

In the following images (Figure 5 and Figure 6) simulation trackplots for the two turning options mentioned above are shown:

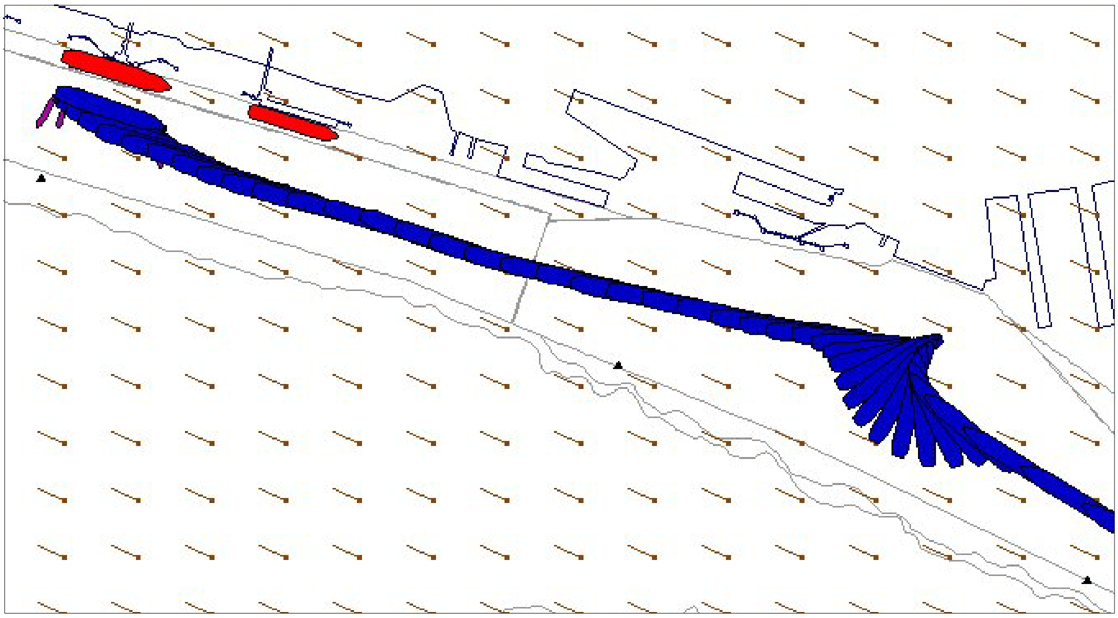

Figure 5. Turning and mooring manoeuvre at Ingeniero White turning basin (Real-time simulator)

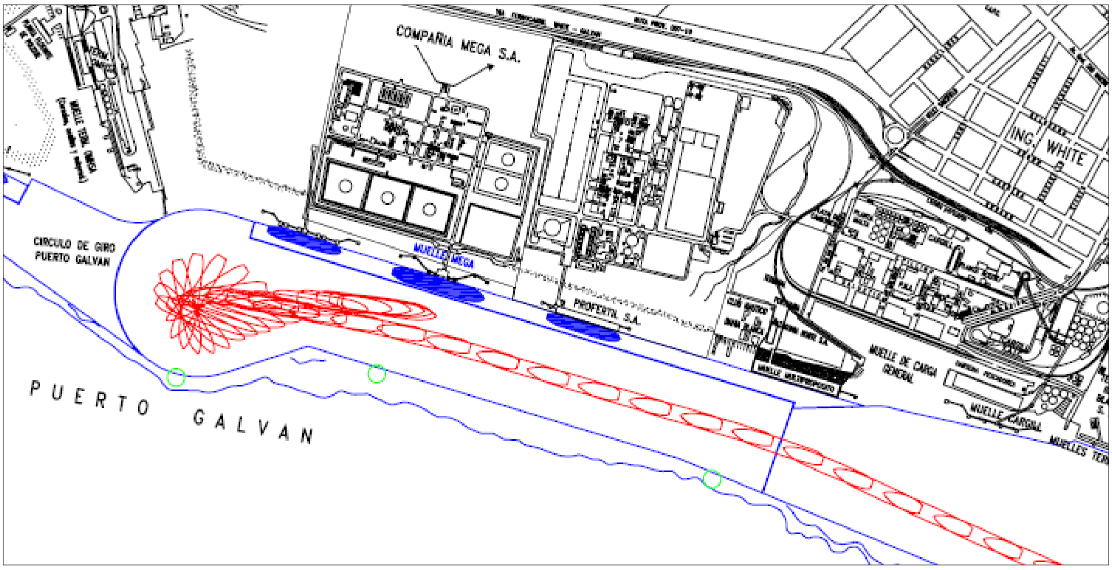

Figure 6. Turning and mooring manoeuvre at Puerto Galvan turning basin (Real-time simulator)

2.2 Mooring and passing ships studies

In this first phase a detailed mooring analysis of the FSRU Excelsior was developed as well: FSRU alone, in order to ensure the survival conditions of the FSRU under extreme wind-current conditions; and with the LNG side by side, in order to determine the limit condition for a safe unloading of the cargo between the vessels. Special attention was given to the relative motions between the manifolds and the mooring and fender loads.

The dynamic response of the moored ship was simulated using the numerical model **SHIP-MOORINGS** developed by Alkyon (Hydraulic Consultancy & Research, The Netherlands). This software simulates the behavior of a specific moored ship under combined conditions of wind, waves and current. The equations of motion of the ship are solved in 6 degrees of freedom (surge, sway, heave, roll, pitch, yaw). Time domain approach is used and no limitations exist for motion amplitudes.

Due to the location of MEGA Terminal, the type of cargo (hazardous cargo) and the fact that the LNG carrier moored side by side to the FSRU stays close to the inner channel of the port, it was necessary to perform a study of the "passing-ship" effect.

The effects of the passing ship upon the moored ship can be explained as the hydrodynamic interaction between the two bodies, also called "suction forces". These are caused by the modification of the flow distribution (and therefore the pressure distribution) due to the presence of both hulls. The layout schemes which were used to carry out the "passing-ship simulations" are shown in figure 7 for both FSRU and FSRU+LNG carrier side by side.

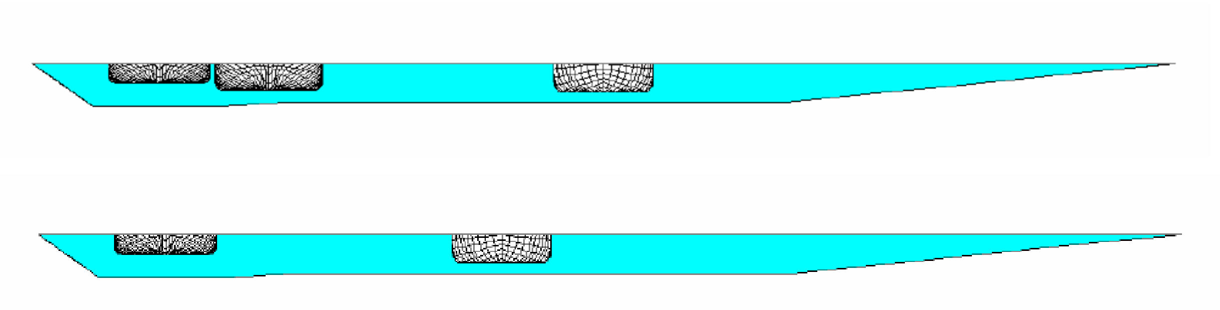

Figure 7. Layout Schemes used in DELPASS Simulations

For the case of a vessel moored at the side of an otherwise straight fairway, the double-body flow is generally adequate for determining the forces due to passing ships. A program was used based on double-body flow, **DELPASS**, developed by J.A. Pinkster, Professor of Ship Hydromechanics at the Delft University of Technology. This program can compute passing ship effects on a moored vessel taking into account the simultaneous effects of one or more passing vessels. The program also takes into account the geometry of the fairway including restricted water depth. The program has been validated by comparing results of computations with model test results carried out by MARIN.

In these "suction forces", the pressure variation (and therefore the forces induced) has typical periods in the order of minutes. These forces are highly dependent on distance and can only be felt in the vicinity of the passing ship (a limited number of ship beams).

This way the interaction forces (suction forces) acting on the moored vessels were analyzed. The design passing vessel considered was the largest tanker operating in the inner part of Bahia Blanca port, Puerto Galvan. Different passing distances (55-70-100-120 m) and speeds (4-5-6-7 knots) were considered. An example of the suction forces curves is shown below on figure 8:

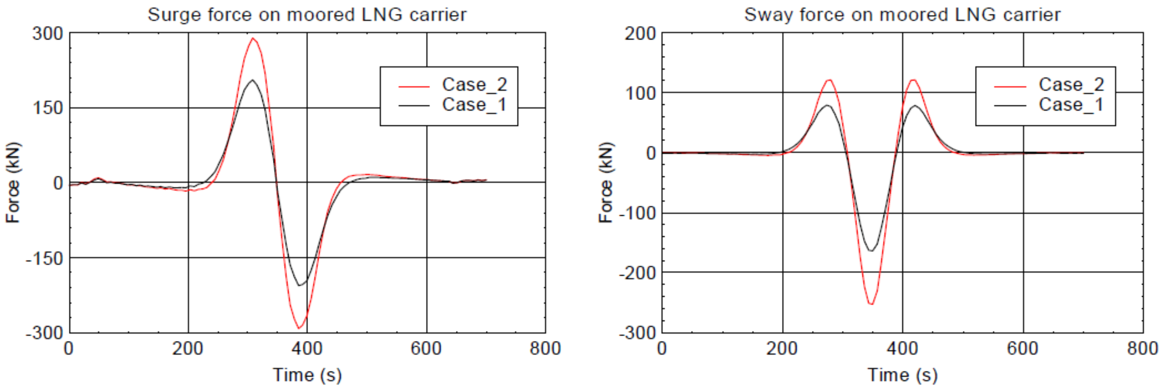

Figure 8. Example of suction forces (surge-sway) curves for different speeds

In this case two different problems have been studied: the first one is the behavior of the LNG moored to the FSRU under the passing forces of the tanker; in a second step, the passing forces over the FSRU are considered together with the forces transmitted through the mooring system. This way a complex problem can be decoupled and solved in an easier way. Another option is to use a multi-body version of the software.

Thus, the limiting curves passing distance-speed were derived. These curves are based on the combined criteria of movements of the moored vessel and loads over mooring lines and fenders. See figure 9 for an example the surge motion limiting curve.

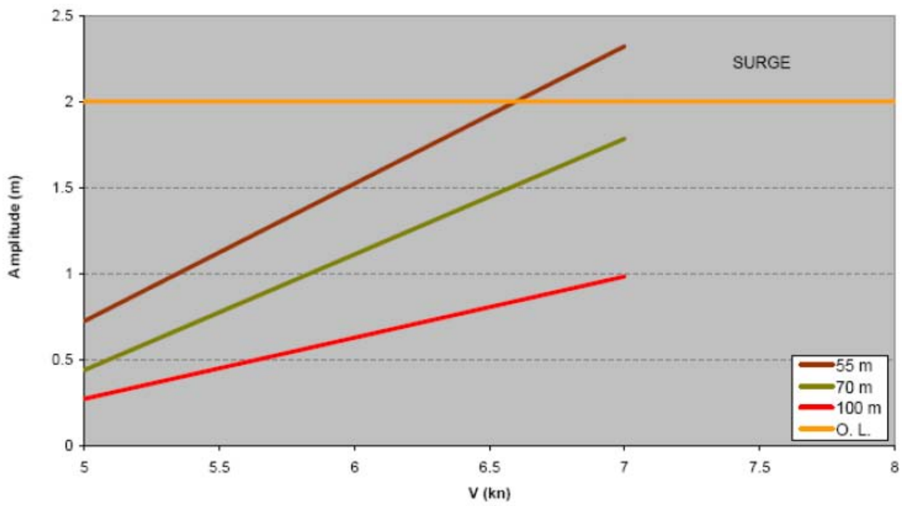

Figure 9. Operation limit FSRU-LNG due to surge motions

The results from the manoeuvring and mooring studies performed allow creating, modifying or incorporating traffic rules for vessels accessing and departure the port. This was used as an input for the traffic flow simulation model which is used to identify the bottlenecks of the traffic flow system and act on them.

3. TRAFFIC FLOW SIMULATION STUDY

The third step in the evaluation of the extension of the port complex Bahia Blanca concerns the traffic flow simulation study.

The objective of the traffic flow simulation study is to identify the bottlenecks of the traffic flow system by analyzing some parameters as: waiting times, quay occupancies, anchorage occupancies, availability of tugs, ...

With the results it is possible to identify which are the main factors affecting the efficiency of the port. The model allows introducing modifications to assess the improvements on the behavior on the traffic flow of the port and therefore find the optimum modifications to be performed.

3.1 Introduction

The capacity of a port system is dependent on the required service level in terms of acceptable waiting times or turnaround times and the safety level. In all ports in the world, a lot of parameters controlling the ship traffic are stochastic of nature. This necessitates the development of probabilistic traffic flow simulation models to estimate the port capacity.

Moreover the approach channel to the port of Bahia Blanca with a length of 92 km and with 5 anchorages is very complex. Ships wait at the anchorages because of berth occupation, tidal conditions and occupation of channel sections. The anchorage use is restricted by the capacity but also by the expected waiting time, destination in the port and the vessel dimensions.

The port itself consists of three main ports viz.

1. Ingeniero White,
2. Puerto Galvan and
3. Puerto Belgrano (with the most important naval base in Argentina),

with 15 terminals in the present situation and is confronted with complex traffic rules.

Based on safety criteria, the output of the manoeuvring simulation study provides traffic rules and manoeuvring strategies, which in turn are used as input for the traffic flow simulation model to determine the capacity of the wet infrastructure.

The model gives results on waiting times, berth occupancies, anchorage occupancy and tug requirements depending on:

1. the vessel traffic volume
2. the quay lengths
3. sailing and manoeuvring times
4. vessel service (transshipment) times
5. wet infra structure with traffic rules
6. disturbances due to tidal conditions and
7. hindrance caused by Mega vessels

3.2 Input data of the model

3.2.1 Wet infra structure Bahia Blanca

The wet infra structure consists of 8 tracks each consisting of a number of sections.

The length of the outer tracks of the approach channel is about 55 nm. At end of each of the first 3 tracks anchorages are located.

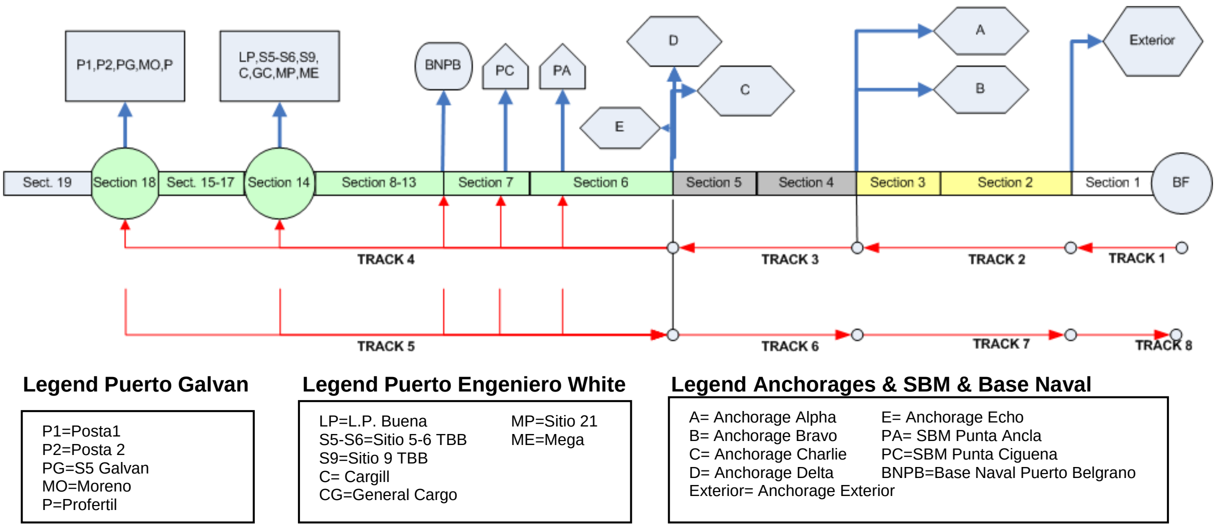

Figure 10: Wet infra structure Bahia Blanca approach channel and wet infrastructure of the port

Figure 10 schematically gives an overview of the tracks and sections in the approach channel and in the port. Moreover this figure shows the terminals with the turning basins Puerto Ingeniero White and Puerto Belgrano, the locations of the Naval Base the locations of the SBM's (Punta Ancla and Punta Cigüeña) and positions of the anchorages.

In 2011 the approach channel has the disposal of 5 anchorages and in the future situation one more viz. the Echo anchorage. The capacities of the anchorages with limitations are given in Table 1.

	Exterior (EX)	Alpha (A)	Bravo (B)	Charlie (C)	Delta (D)	Echo (E)
capacity	no limit	5 ships	3 ships	4 ships	3 ships	2 ships
constrains			only leaving vessels	draught<10m		only for punta ciguena and punta Ancla

Table 1: Anchorages with capacities and limitations

As an example Table 2 shows per channel section the length [nm], the vessel speed [knots], dwell times [minutes] and the sail characteristics of a ship heading for the Luis Piedra Buena terminal. In addition the table gives the location of the anchorages, turning basin and the mooring area of this ship.

Figure 11 and Figure 12 give the present locations of the fairway sections and turning basin in respectively Puerto Galvan (the western part of the port of Bahia Blanca) and Puerto Eng. White (the eastern part of the port).

	track 1	track 2		track 3		track 4										
sections	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	sp1	sp2	sp3	sp4	sp3	sp2
length section	9,84	13,74	4,05	3,87	2	2,98	5,68	2,65	6,42	0,81	0,1	0,32	0,1	turn	0,1	moor
speed section	11	11	11	11	11	11	11	11	11	11	5	5	5	5	5	nr
number section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	13	12
sail/man	sail	sail	sail	sail	sail	sail	sail	sail	sail	sail	sail	sail	sail	man	sail	man
sail direction	inc	inc	inc	inc	inc	inc	inc	inc	inc	inc	inc	inc	inc	inc	out	out
dwell time section	54	75	22	21	11	16	31	14	35	4	1	4	1	30	1	30
totall sail time track	54	97		32		167										
total sail time	320															
		exterior		bravo/alpha		delta/charlie					port entrance					

Table 2: Example tracks and sections per track for an incoming ship of the Luis Piedra Buena fleet

Figure 11: Sections and turning basins Puerto Galvan

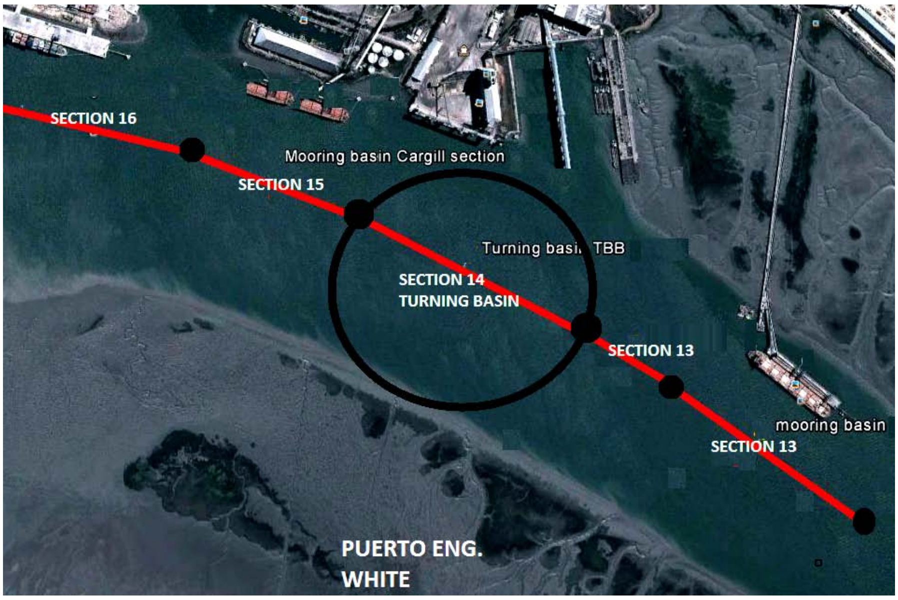

Figure 12: Sections and turning basin Puerto Eng. White

3.2.2 Tidal conditions and water levels

The model is provided with VTS components to check:

a. required water levels,

b. traffic rules on:

    i. one or two way traffic (encounter and overtake rules, with the required safety distance between the vessels)

    ii. rules for the turning and mooring areas

To determine the admissible draught in the shallow parts of the approach channel:

1. section 2 with a draught of 12.80 m and a width 190 m,
2. section 3 the Canal Torre with draught 12.80 m and a width 190 m and
3. sections 8 and 9 (access to Puerto Eng. White) with draught 12.20 m and width 190 m,

The model uses the water levels during spring tide and neap tide. Figure 13 gives the levels in m during spring and neap tide for the Main Channel with reference to Chart Datum.

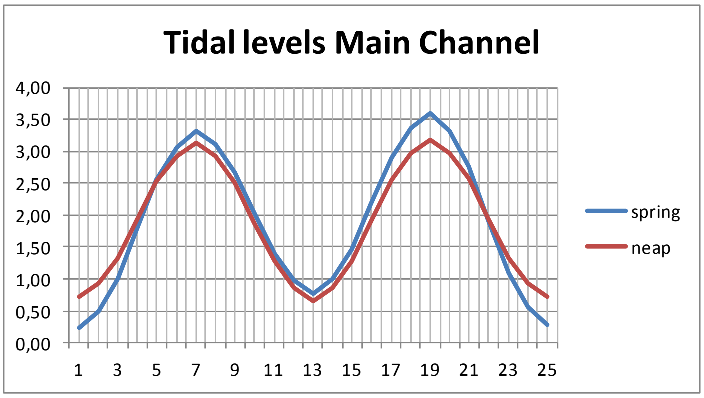

Figure 13: Tidal levels in the main channel

3.2.3 Traffic volumes and position terminals in 2011 and future situation

The annual number of ships per terminal for the year 2011 and the expected number of ships in the future are given in Table 3. Five new terminals will be realised viz. Multigrain, Noble, Vale, LCD Dreyfus and Posta 3 while the Moreno terminal will be renewed (see Figure 14).

This results in an increase of 217 ships per year.

Terminals	2011	future situation
SBM Punta Ancla	93	93
SBM Punta Ciguena	99	99
Base Naval	24	24
Multigrain		70
Noble		70
Vale		60
Luis Piedra Buena	159	40
Toepfer	100	100
Sitio 5-5 TBB	31	31
Sitio 9 TBB	118	118
Cargill	137	137
Sitio 18-20 MMC	35	35
Sitio 21 MMC	61	61
Profertil	37	37
Mega	44	44
Sitio 5 Galvan	25	25
Sitio 2-3 Moreno	84	110
LCD Dreyfus		70
Posta 1	111	111
Posta 2	111	111
Posta 3		40
total	1269	1486

Table 3: Traffic volumes for 2011 and in the future situation

Figure 14: Location terminals in 2011 and in future situation

3.2.4 Traffic rules

The traffic rules have been formulated by taking into account the results of the manoeuvring simulation study and the existing rules.

Rules for encounters and over takings

Encounters and overtake manoeuvres with vessels with a length >250 m are prohibited in the following sections:

1. Between buoys 04 and 10, or section 2
2. Between buoys 12 and 17, or section 4
3. Between buoys 22 and 31, or sections 8 and 9

In case a ship is manoeuvring (turning, mooring or unmooring) no other ship is allowed to be at the same time in this channel section.

Traffic Hindrance by Mega vessels

Mega vessels cause hindrance to the other ship traffic.

When an approach or a departure of a Mega vessel is foreseen the following channel sections are reserved:

a. section 3,
b. sections 8 and 9 and.
c. the sections between section 10 and the turning basin in front of Puerto Galvan

The sections are released as soon as the Mega vessel has passed.

During the time a Mega vessel is moored:

a. no vessels are allowed to pass the Mega terminal with a length>150 (in 2011); in the future situation this rule is canceled because of extended dredged area,
b. if a vessel passes the Mega terminal with a length>100 m this vessel should be assisted by 2 tugs.

Point a. causes high waiting times for the vessels with destinations east of the Mega terminal.

3.3 Description simulation model

The model covers the ship traffic from the arrival buoy, where the ship traffic is generated according to belonging distribution functions of inter arrival times, to the destinations in the port.

The process description method is used, which means that the model consists of a set of inter related components (vessels, VTS, tidal conditions, terminals, etc.) GANS, de O. (2005).The process of each component is described in the module of that component. The stochastic input concerns fleet arrival patterns, dimensions of ships and service times required to load and unload vessels. Erlang_k, Negative Exponential and seasons bound distributions are used to set the attributes of the vessels.

Table 4 specifies the components with the process description of the Bahia Blanca simulation model.

Component	Module name	Process description of the component
Main	Mainmod	Initiates components and read all data of components
Generator	Genprocess	Generates the vessels and assigns the values of the different attributes.
Ship	Shipprocess	Specifies the process of the component ship.
Mega ship	Megashipprocess	Specifies the process of a Mega ship
Dumship	Dumshipprocess	Specifies the process of a dummy ship to reserve a sector at the Bravo and Delta anchorage
Quay master	Qmasterprocess	Checks availability of a berth and allocates berths to requesting vessels.
VTS	Vtsprocess	Checks tidal condition and traffic situation for requesting vessels.
Terminal operator	Termprocess	Registers the service times and prepares departure of the vessel.
Tug	Tugprocess	Specifies the process of the tug
Sectionocc	Occupationsections	Register the occupation of the different channel sections.

Table 4: Modules and components

3.4 Simulation results

3.4.1 Ship waiting times

The waiting times are caused by traffic rules, channel occupation, restricted water levels, quay occupancy and by the constraints set by Mega vessels. Moreover waiting times are influenced by inter arrival time distributions and the service time distributions.

As most of the terminals have only one berth where the ship can be served, waiting time strongly increases when the occupancies exceed 30%, GROENVELD R. (2001).

Present situation (2011)

The waiting time of incoming vessels are for the major part caused by the berth occupancy rate and by constrains set by the Mega vessels, as described above.

In situation 2011, especially the vessels with destinations east of the Mega terminal in combination with high occupancy rates are confronted with high waiting times as the Posta1 and Posta 2 vessels. Also incoming vessels with destinations Luis Piedra Buena, Cargill, are confronted with high waiting times due to a high occupancy rate.

Moreover the waiting times on departure from the terminal are also influenced by the constrains set by Mega vessels.

Future situation

By the cancellation of the rule that vessels with a length of more than 150 m are not allowed to pass the Mega terminal when a ship is moored along the quay of this terminal, the waiting times of incoming Posta 1 and Posta 2 vessels are reduced.

Also because of a strong reduction of the occupancy rate of the Luis Piedra Buena terminal the waiting times of the incoming vessels reduced from about 50 hours to half an hour.

	Situation 2011			Future situation				
Terminals	anchorages inbound	departure terminal	anchorages outbound	anchorages inbound	departure terminal	anchorages outbound	B.O.F 2011 [%]	B.O.F. future [%]
SBM Punta Ciguena	645	43	44	450	3	9	30	31
SBM Punta Ancla	186	81	59	145	5	11	34	32
Base Naval	15	0	6	35	0	6	3	3
Multigrain	-	-	-	27	11	5	-	22
Noble	-	-	-	28	15	5	-	22
Vale	-	-	-	26	11	4	-	35
Luis Piedra Buena	2905	193	4	33	14	4	56	18
Toepfer	-	-	-	31	14	5	-	32
Sitio 5 TBB	24	162	3	27	15	4	7	7
Sitio 9 TBB	196	171	3	103	14	4	33	30
Cargill	1051	141	4	889	13	4	44	41
Sitio 18-20 MMC	19	178	3	30	13	4	1	1
Sitio 21 MMC	45	138	4	40	11	5	9	8
Profertil	461	121	4	224	14	5	13	12
Mega	3	7	2	26	15	1	16	16
Sitio 5 Galvan	260	218	3	74	10	3	18	15
Sitio 2-3 Moreno	1191	233	3	484	12	5	25	25
LCD Dreyfus	-	-	-	91	13	7	-	22
Posta 1	1653	162	3	1476	11	4	54	51
Posta 2	3657	229	3	1456	11	15	63	52
Posta 3	-	-	-	39	17	5	-	16

Table 5: Waiting times in minutes and berth occupancy rates in %

3.4.2 Number of tugs in operation

In the port of Bahia Blanca totally 9 tugs are available of which 7 tugs have a bollard pull of 40 tons or more

	actual situation 2011		future situation	
number tugs in operation	all tugs	40 BP tugs	all tugs	40 BP tugs
0	0	0	0	0
1	5078	5821	4973	5878
2	2377	2545	2307	2448
3	838	289	999	329
4	287	15	298	10
5	134	78	133	80
6	31	12	30	14
7	12	1	16	1
8	2	0	3	0
9	0	0	1	0
total	8760	8760	8760	8760
exceedance	0,0023%	0%	0%	0%

Table 6: Number of tugs at the same time in operation

In both situations (2011 and in the future situation) the maximum number available tugs are sufficient.

Table 6 shows the periods in hours of all tugs at the same time in operation and periods of time of the number of 40 ton Bollard Pull at the same time in operation on average during 1 year.

3.4.3 Number of ships at the anchorages

Table 7 gives the number of ships at the same time at the anchorages for 2011 and the future.

In 2011 only at anchorages Charlie and Delta the number of vessels exceed during a small period of time the capacity of these anchorages.

Despite of the fact that in the future situation more vessels are calling the port of Bahia Blanca, the number of vessels do not exceed the capacity of the anchorages. This is caused by the removal of the hindrance caused by the Mega vessels.

number ships at anchorage	time at anchorage exterior [h]		time at anchorage Alpha [h]		time at anchorage Bravo [h]		time at anchorage Charlie [h]		time at anchorage Delta [h]		time at anchorage Echo [h]	
	2011	future	2011	future	2011	future	2011	future	2011	future	2011	future
0	5849	7853	4582	6913	8554	8605	4804	5358	6737	8245	-	8111
1	1521	770	2027	1329	202	149	1751	2045	1337	354	-	550
2	539	121	1917	366	3	6	1084	865	433	135	-	99
3	307	14	212	114	0	0	634	355	174	23	-	0
4	163	1	21	39	0	0	355	138	71	2	-	0
5	116	0	1	0	0	0	132	0	8	0	-	0
6	91	0	0	0	0	0	0	0	0	0	-	0
7	84	0	0	0	0	0	0	0	0	0	-	0
8	44	0	0	0	0	0	0	0	0	0	-	0
9	30	0	0	0	0	0	0	0	0	0	-	0
10	13	0	0	0	0	0	0	0	0	0	-	0
total	8760	8760	8760	8760	8760	8760	8760	8760	8760	8760	8760	8760
time capacity exceeded [min.]	no limit	no limit	1	0	0	0	132	0	79	2	-	0
percentage of time exceeded	-	-	0.00%	0.00%	0.00%	0.00%	1.51%	0.00%	0.90%	0.024%	-	0.00%

Table 7: Number ships at anchorages

4. EVALUATION OF THE PERFORMANCE OF THE PORT AND AN ESTIMATION OF THE CAPACITY

4.1 Manoeuvrability

A total of 85 different scenarios were covered and 108 simulations were performed, which means more than 60 hours of simulation. The main conclusions derived from the manoeuvring simulations are the following:

1. The available manoeuvring area in the port was considered sufficient, taking into account the evaluation of meteorological limits and tug use. The channel between Rada A and the turning area in Puerto Galvan is wide enough to permit the passage of vessels considered including their respective tug formation.
2. The stopping distance, approximately between buoy number 3 and the West end of the turning area, is considered sufficient under the conditions analyzed, as the ships arrive to the stopping and turning area under control by their own means plus tug assistance.
3. The turning area is considered wide enough to turn around and change course towards the jetty, as far as the manoeuvring strategies are correctly applied. This area allows turning either to port or to starboard, depending on the wind direction and any other circumstances considered by the Pilots.

4. The berthing manoeuvre is carried out with the vessel under control, and the impact velocity of the vessel over the fenders can be controlled with tug assistance and manoeuvring thrusters.
5. The basic tug formation in the final phase of the approach manoeuvres to port was 4 ASD units with a bollard pull of up to 50 tons each. For most of the manoeuvres, two tugs were connected at the bow and stern and the other two at the starboard shoulders

4.2 Moorings and Passing Ships

The main results derived from the mooring and "passing-ships" analyses are the following:

1. Ship motions induced by hydrodynamic interaction ("suction forces") seriously increase with passing ship speed. When speed becomes 50% higher, motion amplitudes get 2-3 times larger under the influence of the maximum ship. Forces in mooring lines and fenders grow as well, but the increase is not so remarkable because of pretension. For the first speed increase, forces grow some 10%.
2. Passing distance is relevant as well. An increase from 70 m to 100 m reduces ship motions by 32% and mooring forces by 10% as an average. Additional increase in distance from 70 m to 120 m causes a 40% reduction in ship motions and 13% reduction in mooring forces as an average. The reduction is more remarkable for higher passing speeds.
3. If a shorter passing distance is considered (55 m) motion amplitudes show a significant increase with respect to the 70 m distance results. Surge, roll and yaw are some 45% to 50% higher, and sway is even 60% higher in average. Forces on some mooring lines and fenders can increase up to 25%-30%.
4. The influence of passing ship dimensions is quite relevant (smaller Lpp=180 m B=31 m vs. maximum Lpp=236 m B=42 m). Suction forces are clearly lower for the smaller ship considering the same passing speed and distance. As an average, moored ship motions are 33% smaller. Line and fender forces are also smaller, in the order of 90%- 94% of those measured for the large tanker. The decrease in motions and forces is more remarkable for higher passing speeds and closer passing distances.

4.3 Traffic flow simulations

The main conclusions derived from the traffic flow simulations are the following:

1. Waiting times
   a. As well as for the existing situation (2011) as for the future situation it is concluded that on average the major part of the waiting times are caused by quay occupancy.
   b. As most of the terminals have only one berth where the ship can be served, waiting times steeply increase when the occupancies exceed 30%.
   c. Reduction of the waiting times in the future situation was caused by the cancellation of the "150 m rule", set by the Mega vessels and also by the reduction of the berth occupancy rate of some terminals.

2. Tugs
   a. In the present situation (2011) and in the future situation the available number of tugs just satisfies the required number of tugs.

3. Anchorage capacities
   a. The present anchorage capacities are only just acceptable for the present traffic volume (2011).
   b. Some improvisation is required for the accommodation of vessels at the Charlie/Delta anchorages.
   c. In the future situation only the Delta anchorage exceeded the capacity during 2 hours on average per year, which can be neglected.

References

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