Geometric Display of Voyage Plan
Geometrijski prikaz plana putovanja

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Summary

A detailed voyage plan must be prepared prior start of the voyage from berth to berth taking into consideration a series of factors which depend on the vessel's size, draught, vessel type, stability, navigation route, meteorological conditions etc. The most important part of the voyage plan for the master and deck officers is the route plotted on a paper and/or electronic navigational chart. Consequently, this paper elaborates on the importance of understanding the utilisation of the major constituent elements when making a geometric display of the navigational route.

KEY WORDS

Route
Turning Radius
ROT
Speed

Sažetak

Plan putovanja obavezno se mora napraviti prije početka putovanja, od veza do veza, uzimajući u obzir čitav niz čimbenika koji ovise o veličini broda, gazu broda, vrsti broda, stabilnosti broda, području plovidbe, meteorološkim uvjetima i dr. Najvažniji dio plana putovanja za zapovjednika i časnike palube je ucrtana ruta na papirnatoj i/ili elektroničkoj pomorskoj karti. U radu je objašnjena važnost razumijevanja i korištenja osnovnih konstitutivnih elemenata pri geometrijskom prikazu rute.

KLJUČNE RIJEČI

ruta
polumjer kružnice okreta
brzina promjene kursa
brzina

INTRODUCTION / *Uvod*

It is essential to develop a voyage plan prior to departure. This is stipulated in the SOLAS Convention Chapter V without specifying the elements of voyage plan but indicating the need for the plan to be prepared in accordance with IMO "Guidelines for Voyage Planning"[1]. Voyage planning, according to these Guidelines, involves appraisal (gathering information about the intended voyage); detailed planning of the entire voyage "from berth to berth" including pilotage as well; execution of the plan; and monitoring the progress of the voyage without stipulating the constituent elements of the route. In ICS[2] publication "Bridge Procedures Guide" constituent elements of the route are stated and the procedure for marking and plotting the route on a paper or electronic navigational chart.

LEGAL REGULATIONS FOR VOYAGE PLANNING / *Pravna regulativa planiranja putovanja*

Regulation 34 „Safe navigation and avoidance of dangerous situations" [3] Chapter V of the SOLAS Convention applies to all ships regardless their size. This Regulation stipulates that the voyage plan should be developed prior to departure by using relevant navigational charts and publications for the intended voyage. Vessel's position should be plotted and vessel's movement monitored during the entire voyage. ECDIS[4] can be taken as the means of fulfilling this requirement. According to Regulation 34 the voyage plan must determine the route taking into consideration the ship's routing system ensuring a safety margin for safe navigation, anticipating the possible navigational hazards and adverse weather conditions, taking into consideration the environmental protection and avoiding any action that may present an environmental hazard.

Regulation 34-1 Master's discretion stipulates that it is the master who has the absolute authority to decide what is best for safe navigation and environmental protection. According to this Regulation the master's discretion in decision making shall not be compromised under any circumstances.

IMO Resolution A.893(21) "Guidelines for Voyage Planning" stipulates that it is of utmost importance for safety of life at sea, safe navigation and protection of the environment to plan and continuously monitor the ship's progress and position during execution of the voyage plan.

The requirement for voyage planning applies to all vessels. There are also the factors applying to all vessels and factors applying only to large vessels or vessels carrying hazardous cargoes. Voyage planning involves appraisal (gathering information about the intended voyage); detailed planning of the entire voyage "from berth to berth" including pilotage as well; execution of the plan; and monitoring the progress of the voyage.

According to this Resolution the voyage plan should take into account the vessel's condition, stability and equipment; any operational limitations; permissible draught at sea in fairways and in ports; vessel's manoeuvring abilities. Furthermore, special properties of cargo should be taken into account (in particular if hazardous cargoes are being carried), distribution, stowage and securing the cargo on board. The crew should be competent and well-rested. There are also requirements concerning up-to-date certificates

[1] Guidelines for voyage planning (IMO Resolution A.893(21))
[2] International Chamber of Shipping
[3] SOLAS, Chapter V, Regulation 34, „Safe navigation and avoidance of dangerous situations"
[4] ECDIS (Electronic Chart Display and Information System)

and documents concerning the vessel, her equipment, crew, passengers and cargo. Also, navigational charts (either paper of electronic) to be used during the voyage must be accurate, up-to-date and used in the appropriate scale. Notices to mariners and radio navigational warnings, either temporary or permanent, must be applied. In addition, accurate and up-to-date sailing directions, lists of lights and lists of radio aids to navigation should be checked.

It is also necessary to analyse hydro-meteorological data available in various publications, meteorological services for weather routing, routing and reporting systems, pilotage and available port information.

When planning a voyage, according to this Resolution, it is necessary to plan the entire voyage from berth to berth including the parts of voyage with pilot on board.

Such detailed voyage plan should include:

1. The plotting of the intended route on appropriate scale chart. The true course should be indicated. In addition, all areas of danger, the existing ships routing systems, reporting systems, vessel traffic services and marine environmental protection areas should be indicated.
2. The main elements (but not limited to) ensuring safety of life at sea, safety and efficacy of navigation and protection of the marine environment are:
    1. safe speed, taking into account the proximity of navigational hazards along the intended route, manoeuvring abilities of the vessel and her draught in relation to the available water depth;
    2. required speed alterations en route where there may be limitations due to voyage during night, tides or permissible draught increase due to squat and heel effect when turning;
    3. minimum clearance under the keel in critical areas with restricted water depth;
    4. position where a change in the main machinery status is required;
    5. course alteration points, taking into account the vessel's turning circle at the planned speed and expected effects from tide and sea currents;
    6. the method and frequency of position fixing, including the primary and secondary options; it is necessary to indicate the areas where accuracy of position fixing is critical and maximum reliability required;
    7. use of the ships' reporting and routing systems and vessel traffic services;
    8. environmental protection;
    9. in case of emergency when change of voyage plan is necessary the vessel should be placed in deep water or port of refuge or safe anchorage taking into consideration shore-based emergency response procedures and equipment as well as the nature of the cargo.

Pursuant to the Resolution the details of voyage plan should be clearly marked and duly recorded on navigational charts and voyage plan notebook or PC hard disk. Each voyage plan must be approved by the master prior to the commencement of the voyage.

The part of the Resolution referring to "Execution" states that as soon as ETD (estimated time of departure) and ETA (estimated time of arrival) are determined with reasonable accuracy the voyage may start. When executing the voyage plan due consideration should be given to the following factors:

1. reliability and condition of navigational equipment
2. estimated times of arrival at critical points for tide heights and flow
3. meteorological conditions (in low visibility areas in particular) and weather routing service
4. day-time and nigh-time navigation through hazardous areas and any effect this may have on position fixing accuracy
5. traffic conditions

The master should consider whether there are any special circumstances such as forecast of restricted visibility in the region where visual technique is used as the major element of the voyage plan which would lead to unacceptable hazard for safe navigation according to the voyage plan and whether to navigate through such regions under the prevailing conditions. The master should also consider when to designate more men on the bridge or in the engine room.

The„Monitoring the progress of the voyage" part stipulates that the voyage plan should be available at the bridge at all times during the voyage to provide the officers on watch with immediate access to the plan. The vessel's progress according to the voyage plan must be monitored at all times. Any changes in voyage plan must be consistent with these Guidelines and clearly marked.

The ICS publication „Bridge Procedures Guide" points out the constituent elements of the route. Consequently, the chapter 2.3.3 *The passage plan* states that the passage plan should incorporate the following data:

- the planned route showing the true course of each leg
- leg distances
- any speed changes
- wheel over positions for each course alteration, where appropriate
- turn radius for each course alteration, where appropriate
- maximum allowable off-track margins for each leg

GEOMETRIC DISPLAY OF ROUTE / *Geometrijski prikaz rute*

Chart display of route is the most important part of voyage planning, either on paper charts or using electronic chart display.

When using electronic chart display the advantage of ECDIS is that an estimate of the safety of route can be made according to the criteria set up in advance. When using the traditional paper charts the safety relies on the human factor.

Modern approach to voyage planning using ECDIS enables the geometric display of route by using the turn radius. The minimum value of the turn radius is set up in the system according to the manoeuvring abilities of a vessel. This involves the track mode as well as the vessel's manoeuvring abilities under such mode.

Turning with constant turn radius / *Okret broda sa stalnim polumjerom kružnice okreta*

A body when turning keeps constant distance (r) from the centre (S). In circular movement the track is a curve. The curve

is bordering a circle. The speed (v) is calculated by dividing the distance passed (the distance is a curve (Δs) and time (t).

Speed on the circumference is a vector. In space both the value and the direction are to be taken into account. The distance and radius form the right angle (Figure 2). The vector of speed is vertical to the radius or the speed is tangential since it is on the line which is a tangent to the curve.

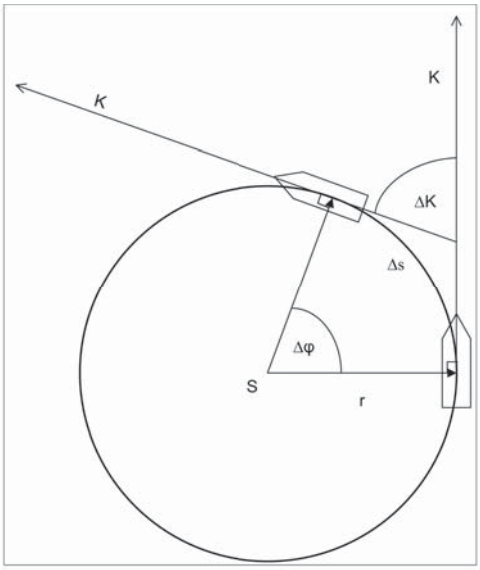

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Figure 1 Circumferential speed
Slika 1. Obodna brzina

The vector from the centre of the track curve to the object on the track is called the *position vector* or *radius vector*. The *position vector* turns together with the object. Its length crosses the movement line and "swipes" an angle. The angle speed is the swipe angle (Δφ) divided by time (Δt) and it is marked as ω.

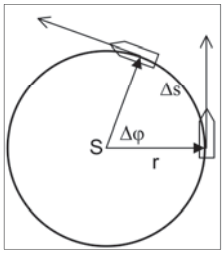

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Figure 2 Angular speed
Slika 2. Kutna brzina

When the planned course and the new course meet as tangents on the turn radius and the vessel follows the curve between points of tangency the ship will be on the desired new course.

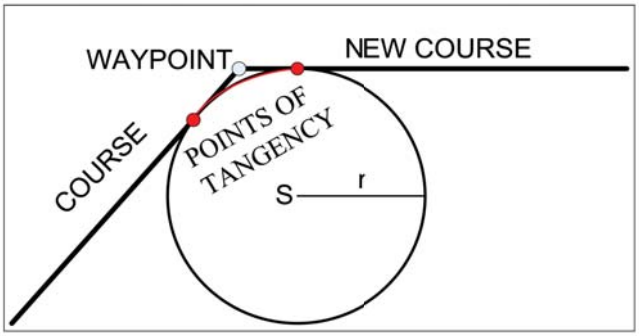

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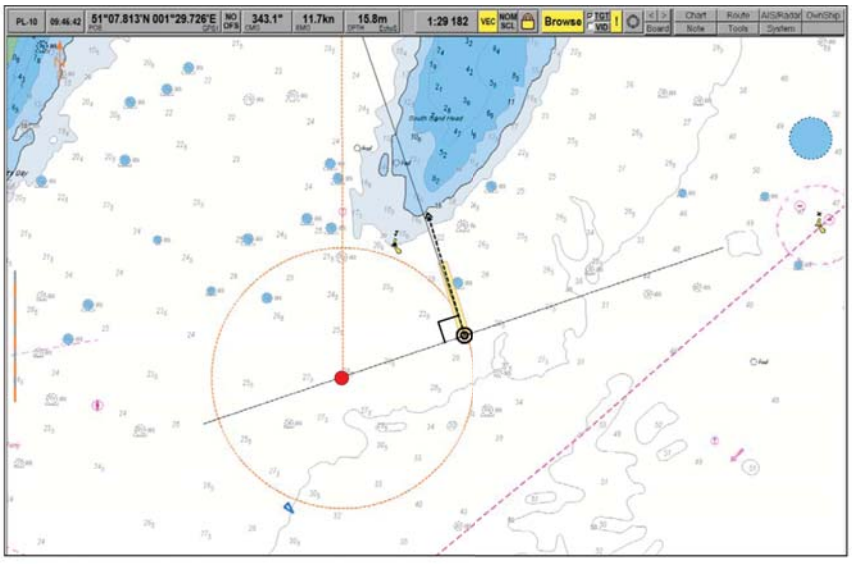
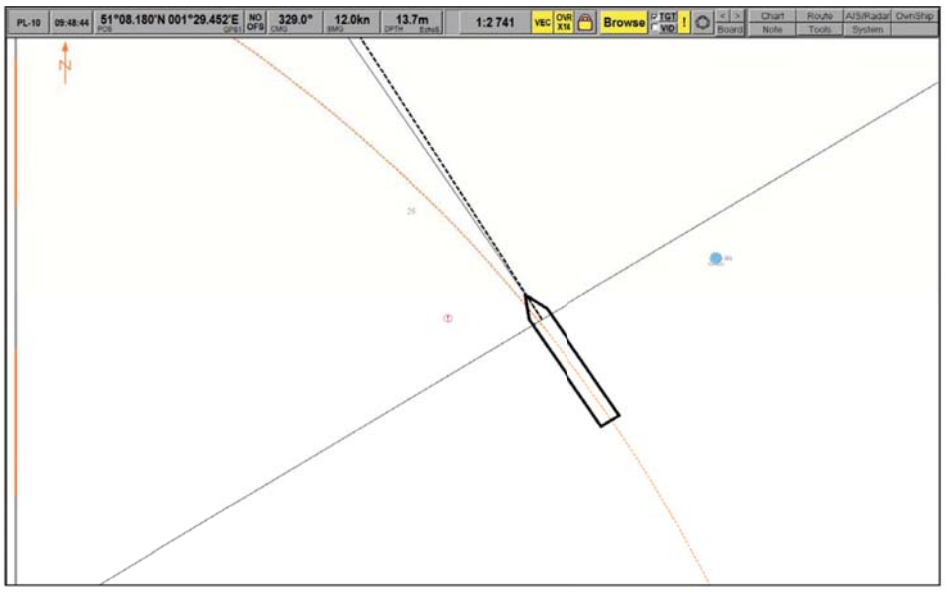
Figure 3 Section of the turning radius
Slika 3. Dio kružnog luka kružnice okreta

If the vessel must be at the curve between the points of tangency the turn must be performed without altering the turn radius. In shipping, to keep the vessel at the curve between the points of tangency it is necessary to keep the relative bearing 90° from the fixed object and thus to keep the distance from the centre (fixed radius). The points of tangency represent the wheel over position.



Source: author, reference from ECDIS K-BRIDGE

Figure 4 Navigation on turn radius
Slika 4. Plovidba po kružnici okreta



Source: author, reference from ECDIS K-BRIDGE

Figure 5 Setting the stern angle line

Slika 5. Postavljanje linije pramčanog kuta na vlastiti brod

Modern equipment enables geometric display of relative bearing +/- 90° in relation to our ship shown as a symbol (Figure 4) or in scale (Figure 5). The aim is to have the centre of the circle under the 90°angle (over-side) and thus follow the turning curve.

ROT (*Rate of Turn*)

ROT represents the rate of change of course and it is shown in degrees per minute. That is the angular speed of the ship. ROT depends on the value of the vessel's speed (circumferential speed) and turn radius. The angle at the centre of turn angle (Δφ) corresponds to the change of course (ΔK) as shown in Figure 2.

$$\Delta\varphi = \Delta K \quad (1)$$

$$\Delta\varphi \; r = \Delta s \quad (2)$$

$$\frac{\pi}{180} = \frac{\text{rad}}{\text{deg}}$$

$$\pi \text{ deg} = \text{rad } 180$$

$$\text{rad} = \frac{\pi \text{deg}}{180}$$

$$\Delta\varphi \; \frac{\pi}{180} \; r = \Delta s \quad (3)$$

$$\Delta\varphi \; \frac{\pi}{180} r \; = v \; t \quad (4)$$

$$\frac{v}{r} = \frac{\Delta\varphi\pi}{180t}[°/h] \quad (5)$$

$$\frac{\Delta\varphi\pi}{180t} = \frac{v}{60r}[°/\text{min}] \quad (6)$$

$$\frac{\Delta\varphi}{t} = \frac{180v}{60\pi r}[°/\text{min}] \quad (7)$$

$$\frac{\Delta\varphi}{t} \approx \frac{v}{r}[°/\text{min}] \quad (8)$$

ROT $\approx \frac{v}{r}$ [°/min] (9) where v is shown in knots, r in miles, t in minutes, φ in degrees

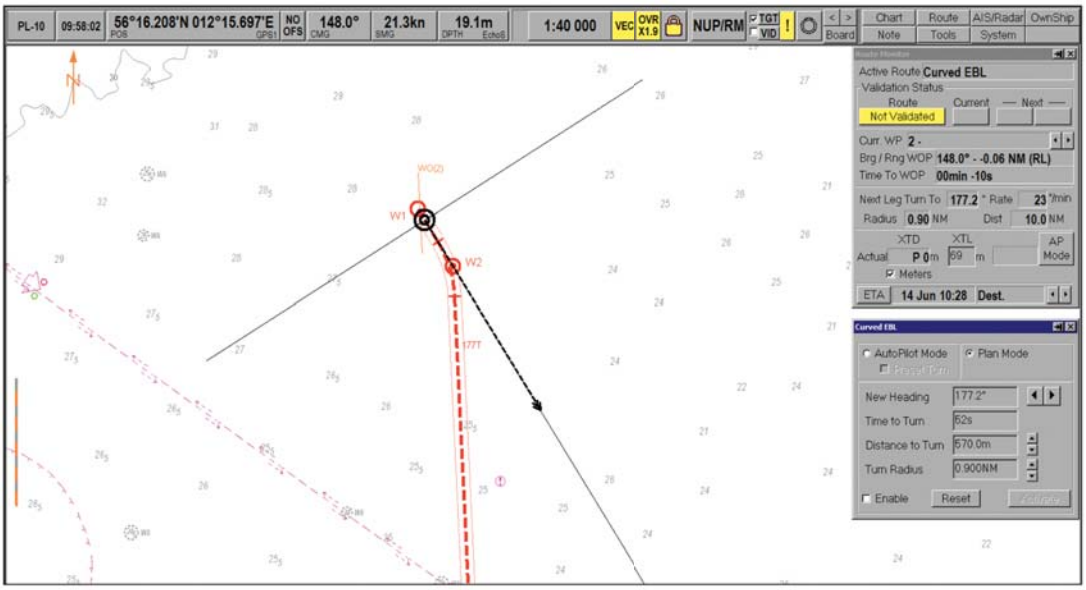
The expression (7) is the correct formula of the relation between ROT, speed and turn radius. In practice the approximate formula (8)/(9) is used where the value π is rounded to number 3.

Pursuant to Regulation 19 "Carriage requirements for ship-borne navigational systems and equipment", SOLAS Chapter V, all ships from 10 000 GRT and more, along with other requirements, shall be fitted with the system indicating course through the water and over the ground, or another device for automatic control and keeping course through the water and/or over the ground. All ships of 50 000 GRT and more shall, along with other requirements, be fitted with a rate of turn indicator (ROT), or another device showing the values of course change speed.

The minimum turn radius is determined for each vessel representing a limiting factor when planning the route.

The aim is to obtain the optimum ratio between speed, radius and speed of course change. In practice a large ROT means a large heel which have a negative effect on the ship and cargo, consequently, as small as possible ROT with respect to prevailing circumstances is required. The speed of course change depends on the vessel's speed and turn radius – by reducing the speed and keeping the constant radius or by increasing the turn radius and keeping the constant speed the speed of course change is reduced.

Modern navigational equipment provides the possibility to predict the vessel's movement, as shown in Figure 6.



Source: author, reference from ECDIS K-BRIDGE

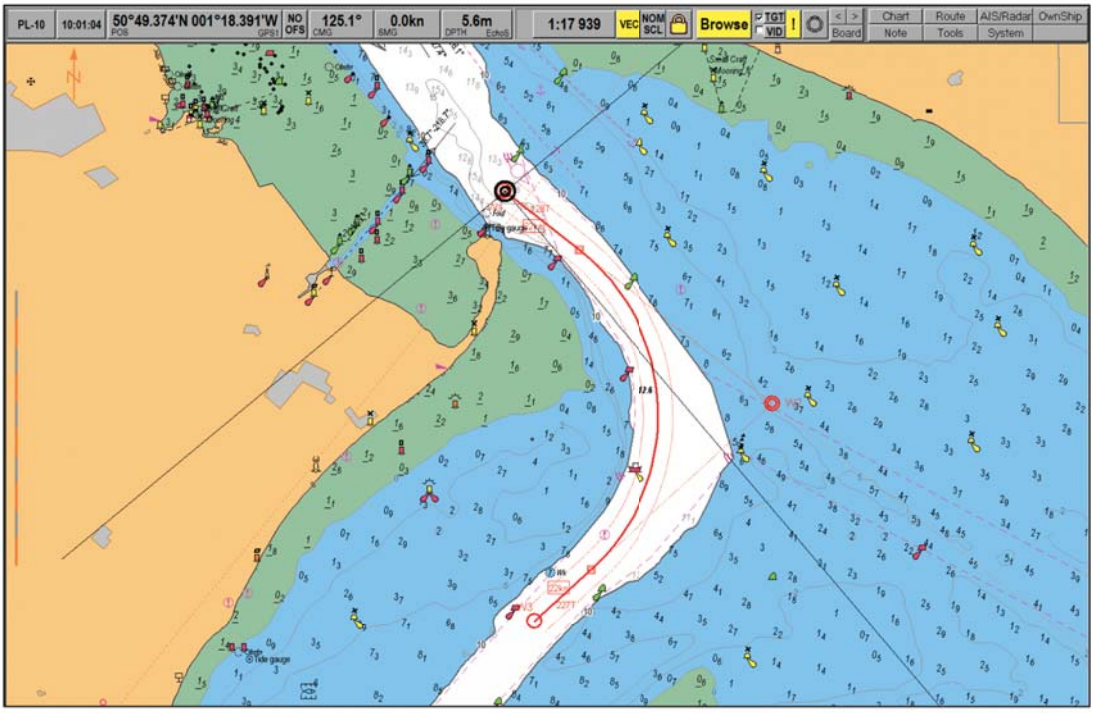
Figure 6 Geometric display of vessel's movement on the basis of turn radius

Slika 6. Geometrijski prikaz kretanja broda na temelju polumjera kružnice okreta

The Figure 6 shows a geometric display of the planned route. The curved EBL can be used twofold: Auto Pilot Mode and Plan Mode, as used in ECDIS K-Bridge. Thus the master and deck officers are able to see the intended route with respect to the turn radius. The value of turn radius changes (from minimum fixed and higher) and together with the new course and time until turn or distance until turn it is used for plotting on electronic charts.

When choosing the size of turn radius in a waypoint due consideration should be given to the following elements:

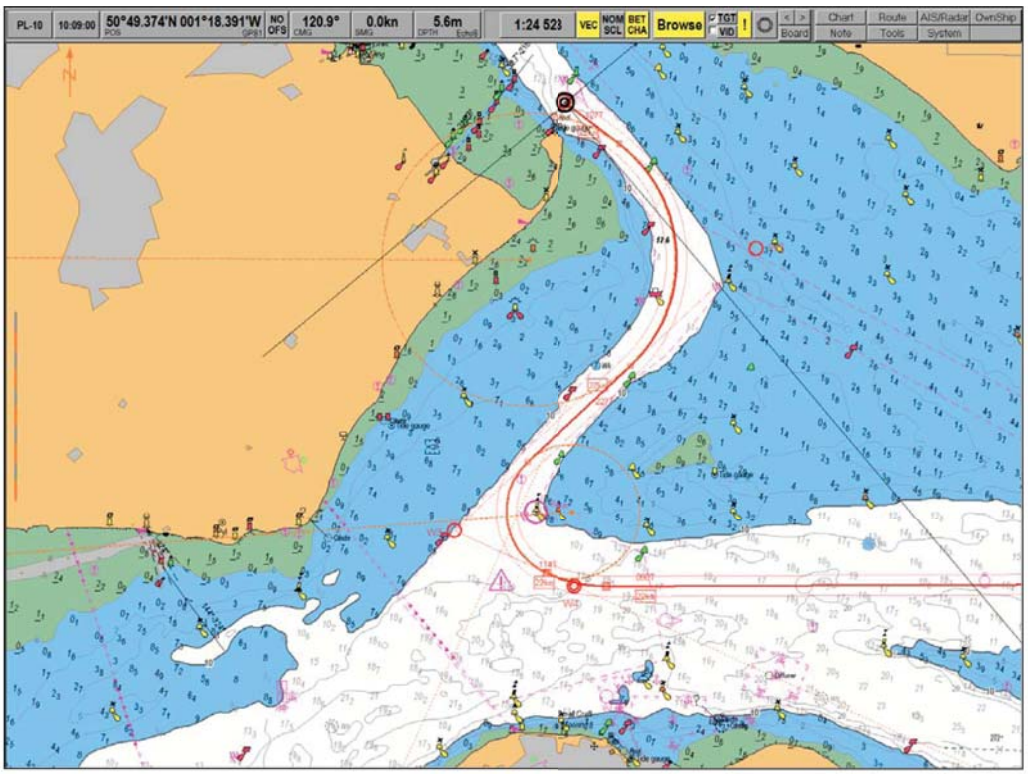
a) turning curve must not be over the ground, shallow waters and similar navigational hazards
b) turn radius could show the waypoint over the ground, in shallow waters and similar navigational hazards (Figure 5)



Source: author, reference from ECDIS K-BRIDGE

Figure 7 Radius as the main element of geometric display of voyage plan

Slika 7. Polumjer kao osnovni element geometrijskog prikaza plana putovanja



Source: author, reference from ECDIS K-BRIDGE

Figure 6 Combination of curves for different size radii

Slika 6. Kombinacija kružnica okreta za polumjere različite veličine

c) turn radius must provide for the point in which the planned route is changing from circular into linear not to fall within the circular navigational route of the next turn. Between two circles of two turn radii there has to be a linear navigational route.
d) turn radius should be as large as possible taking into account the requirement for maximum speed and reduced number of legs
e) turn radius should be adapted so that in combination with the planned speed it produces the minimum but acceptable ROT (from the steering aspect).

The problem in geometric display of route may occur when the route data including the waypoints are transferred from ECDIS to GPS with the installed voyage planning programme. The GPS will calculate the distances and courses on the basis of waypoint positions without taking into consideration the geometric display of the route on the chart. In this case discrepancies may occur between the routes calculated as geometric display on an electronic chart where distances are calculated according to turn radius and GPS. Moreover, the waypoints on the electronic chart could be shown on the ground, in shallow waters and similar navigational hazards and thus the application of GPS may lead to peril.

CONCLUSION / *Zaključak*

Modern navigational systems facilitate voyage planning, in particular the chart plotting part.

In comparison with the traditional plotting on paper charts the geometric display on an electronic navigational chart automatically considers the given manoeuvring abilities of a vessel.

The problem is the position of the way points of the route which no longer have to be on the safe navigational route but, to the contrary, may be on the ground, in shallow waters and similar navigational hazards.

Modern equipment requires modern approach to safety of navigation. Consequently, the more ECDIS is being used there will be more such routes, which was until recently impossible, in particular with modern navigational systems being used in navigation.

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SOLAS, Chapter V, Regulation 34-1, „Master's discretion"

SOLAS, Chapter V, Regulation 19, „Carriage requirements for ship-borne navigational systems and equipment"

EQUIPMENT

ECDIS (Electronic Chart Display and Information System) K-Bridge manual, Polaris Ship Bridge Simulator, Kongsberg