THE DANUBE WATERWAY TRANSPORT AS 'EXTENDED LEG' OF MARITIME TRANSPORT ACROSS SHIP LOCKS – CASE STUDY: SHIP LOCK IRON GATE 1

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Abstract:

The ship locks are most important infrastructural objects for traffic and transport on Danube navigable network. In operational sense they are the obstacles for inland navigation. It means they limit the Danube waterway transport and fleet capacities.

The ship locks in the function of using inland navigation on the Danube River present in first part of this paper. The number of ship locks on the Danube River are following: the Upper Danube (15 dams each with two standardized locks with one lock chamber), the Middle Danube (1 dam with two standardized locks with one lock chamber and 1 dam with two standardized locks each with two lock chambers) and the Lower Danube (1 dam with two standardized locks with one lock chamber). The authors research the individual ship lock capacity for 12 ship locks, mainly on the Upper Danube, depending upon the state of lock chamber and performances of each locks, kind of inland vessels/barge tows and upstream and downstream navigation.

In second part of this paper considers the restoration of Serbian ship locks: Iron Gate 1. The Serbian ship lock on right bank of Danube River operate in pair by the Romanian ship lock on left bank of Danube River. Their capacities analyze depending on the distribution of vessels/barge tows in front of dams and in back of dams (upstream and downstream navigation).

Keywords:

Eco/Co/multimodal transport; Inland navigation and ship locks on Danube River; Ship lock capacity; Ship time passing across ship lock.

1. INTRODUCTION

The basic characteristics of inland waterway transport development from 2010 to 2020 in the Danube Region are following:

- Strengthening and growth of road transport, especially in foreign trade increasing road transport in long distances in competition with other transport modes.
- Stagnation and relative decrease of Danube inland waterway transport in freight transport activities.
- All better results in pipeline transport causing decrease of liquid cargo traffic in Danube inland navigation.

This state follows the infrastructure in all transport modes, in other words, road network and pipelines many faster develop than rail trucks and inland waterways in the Danube Region.

The current transport utilization of the remaining Danube amounts 7 to 10% of its maximum theoretical/potential capacity. The main explanation for it lies in the economic framework conditions in the Danube catchment areas. Additionally, Danube navigation is presently faced with temporarily limited and fluctuating droughts at some sections, which affects its competitive position. Removal of the unfavorable fairway conditions on the Danube would therefore also contribute to the optimized exploitation of Danube's potential. [1]

The relationship between Danube waterway transport and Danube hydrological regime is given by the fact that vessels sail through the fairway built in Danube River and vessels' capacity transport depends on the water depth and width of fairway's sections. In the fact, the relationship between water depth and vessels' loading capacity is direct: the lower water depth, the lower vessels' carrying capacity.

On the other side, the International Commission for the Protection of the Danube River – ICPDR talks about negative effects due to climate change in the Danube River Basin including Danube fairway and Danube waterway transport:

- Measures in the past were not successful and current Danube River Management will not be successful to stop bed level degradation.
- Due to ongoing process to bed level degradation, water depth might decrease up to 0.6 m around 2030.
- Ongoing bed level degradation could have great impact on Danube waterway transport, especially at river locations with fixed layers.
- Sediment deficit in the Danube due to damming and regulation works repeated. The issue of sediment deficit remained open. [2]

It means the Danube infrastructural adaptation strategies have to involve all those physical measures aimed to modify ship locks such as the Iron Gate 1 including other ship locks along the Danube fairway.

The remainder of this paper is organized as follows. The section 2 provides a introduced consideration with a review of ship locks on Upper, Middle and Lower Danube. In the section 3 deals with a average lockage time, mainly on the Upper Danube. The section 4 includes the analysis of lock operations of Serbian and Romanian ship locks Iron Gate 1. In the section 5 cost of lockage is analyzed in frame of the Serbian ship lock Iron Gate 1. The economic analysis: savings after restoration of Serbian lock Iron Gate 1 are presented in the section 6. The section 7

describes the evaluation of air pollution and noise in area of Serbian lock Iron Gate 1 after adaptation (environmental conditions). This paper concludes with the section 8 and future research directions are suggested.

2. SHIP LOCKS ON UPPER, MIDDLE AND LOWER DANUBE

On international Danube fairway across ten riparian countries, from Kelheim, river kilometer- rkm 2414+840 to Sulina, rkm 0.000 (the junction of Danube in Black Sea) built 18 ship locks, from which 14 locks arranged in pairs at hydroelectric power stations (dams) as parallel, symmetrical or asymmetrical, standardized ship locks.

Four ship locks on Upper Danube (German part of Danube) are with one lock chamber for commercial vessels. Two locks have particular lock chamber for recreational vessels (dimensions

of chamber: 20x4.0 m). From 18 ship locks 17 are with one longitudinal lock chamber (single step) including access canals on both sides of lock chamber (upstream and downstream direction), pre-berths at ship locks and other equipment for surmount of water height between up and down water levels in the chamber. This height varies between 7 and 17 m excepting Serbian and Romanian ship locks Iron Gate 1. The ship locks Iron Gate 1 are only with two longitudinal chambers (two-step) for surmount of difference of water levels in first chamber (in downstream direction) of 17.5 m and in second chamber of 17 m. [3]

According to the characteristics of Danube fairway (longitudinal fall and velocity of water stream) 15 ship locks arranged on the Upper Danube (5 in German part of Danube and 10 in Austrian part of Danube). There are on average, mutual distance of 24.28 km in Germany and 31.23 km in Austria along Danube waterway. Also, the work of these ship locks depend on common operations, since lockage in one ship lock (for example, first lock in upstream direction) has the impact on the operations of other ship locks in both upstream and downstream directions.

On the Middle Danube built two dams: Gabčikovo (rkm 1819+150) with two ship locks Slovakian and Hungarian locks and the Iron Gate 1 including Serbian lock on right bank (rkm 942+950) and Romanian lock on left bank (rkm 942+950).

On the Lower Danube built one dam Iron Gate 2 with two ship locks the Serbian lock on right bank (rkm 863+000) and Romanian lock on left bank (rkm 863+700). The distance between Iron Gate 1 and 2 is approximately 80 km.

All Danube ship locks presented in the Table 2.1 with locations on the Danube waterway, dimensions of lock chamber, minimum depth on threshold of lock chamber and maximal allowed dimensions of barge tows/convoys.

The total lockage time of vessel/barge tow/convoy encompasses following times: the times of opening and closing lower and upper gates of lock chamber, the enter/exit times of vessels/barge tows/convoys to and from lock chamber, the preparation times with maneuvers for berthing and unberthing to and from lock bollards (in lock chamber) and times of water filling/discharge in lock chamber. [4]

In other words, passing times of vessel/barge tow/convoy through the lock depend upon numerous variables. The states of the lock chamber change as result of the following basic operations:

I. Upstream direction

(1) Closing of the gates at the lower lock head.

(2) Filling the chamber with water.

(3) Opening of gates at the upper lock head.

II. Downstream direction

(1) Closing of the gates at the upper lock head.

(2) Discharge of water from the chamber.

(3) Opening of the gates at the lower lock head.

Table 1 – Ship locks on Upper, Middle and Lower Danube.

Name of ship lock	**Distance from Sulina in rkm**	**Dimensions of lock chamber**		**Minimal depth on threshold, m**	**Maximum allowed dimensions of barge tow**	
		Length m	**Width m**		**Length m**	**Width m**
BAD ABBACH	2397+170	190	12	4.00	185	11.40
REGENSBURG	2379+680	190	12	4.00	185	11.40

GEISLING	2354+290	230	24	4.00	230	22.80
STRAUBING	2324+330	230	24	4.00	230	22.80
KACHLET	2230+330	230	24	2.50	230	22.80
JOCHENSTEIN	2203+330	230	24	5.22	230	22.80
ACHACH	2162+670	230	24	4.61	230	23.00
OTTENSHEIM	2146+820	230	24	3.97	230	23.00
ABWINDEN	2119+540	230	24	4.39	230	23.00
WALLSEE	2095+060	230	24	4.29	230	23.00
YBBS-PERSENBEUG	2060+420	230	24	4.15	230	23.00
MELK	2038+060	230	24	3.41	230	23.00
ALTENWORTH	1980+110	230	24	4.69	230	23.00
GREIEFENSTEIN	1949+200	230	24	4.15	230	23.00
FREUDENAU	1921+050	275	24	4.87	275	23.00
GABČIKOVO	1819+150	280	34	5.00	275	23.00
IRON GATE 1	Right bank	310	34	5.00	300	33.00

	942+950					
IRON GATE 1	Left bank 942+950	310	34	4.50	300	33.00
IRON GATE 2	Right bank 863+000	310	34	4,50	300	33,00
IRON GATE 2	Left bank 863+700	310	34	5.00	300	33.00

Source: Radmilović, 2007, p.61 [3].

The lockmaster on duty controls these operations, as well as, the signaling system ahead of the lock and within the chamber itself, thus being able to halt the vessel/barge tow/convoy ahead of the lock, for example, due to lock/chamber occupancy or within the chamber due to failures of the lock elements and similarity. [4]

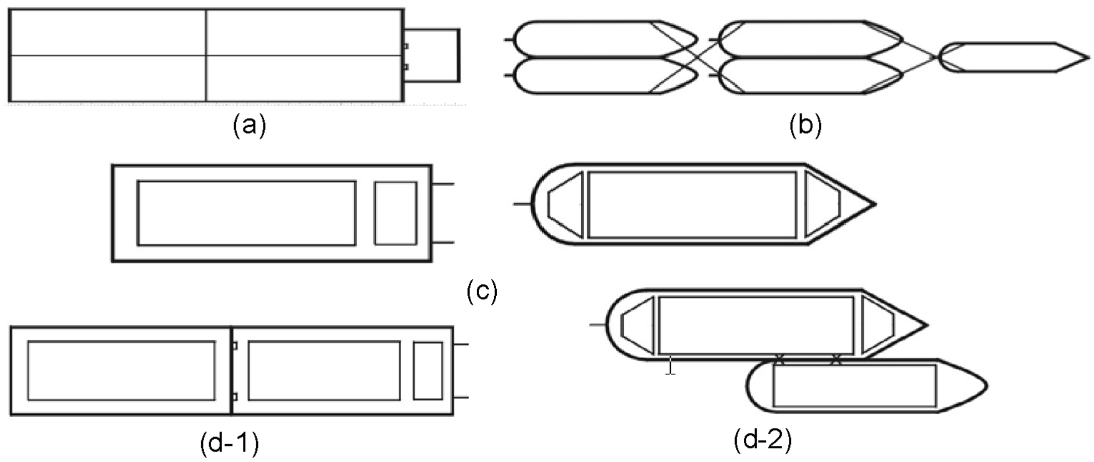
3. AVERAGE LOCKAGE TIME ACROSS SHIP LOCKS ON UPPER DANUBE

The total lockage time has been measured in vessel/barge tow from moment of reducing speed (lighten power of main engines) in front of the ship lock to the moment of full power of vessel (main) engine(s) on the second side of lock in both directions of navigation (upstream and downstream). The measures performed in the period 1978-1984 within all three systems of transportation technology on Danube River:

- Push towing system.
- Pull towing system
- Self-propelled barge including combinations with pushed and pulled barges.

The Danube cargo fleet is presented in Fig. 1 depending on the Danube transport technology [5].

Figure. 1. Types of freight ships/barge tows in Danube navigation.



(a) Pushed barge tow with push boat;

(b) Pulled barge tow with pull boat;

(c) Self-propelled barge or freight motor ship;

(d) 1 – Self-propelled pushed barge with pushed barge in tow;

2 – Self-propelled pulled barge with pulled barge in tow.

The total lockage time of push/pull barge tows and self-propelled barge could calculate as follows [3]:

$$t_{up} = t_{um} + t_{px} + t_p + t_{px}' + t_{im} \qquad \ldots (3.1)$$

where

t_{up} = total lockage time, min;

t_{um} = enter time of vessel/barge tow/convoy in lock chamber with maneuvers, min;

t_{px} = prepared time of vessel/barge tow/convoy for lockage (connecting of vessel/barge tow/convoy for bollards on chamber's walls) and time of closing of lower/upper gates in depending on navigable direction, min;

t_p = filling/discharge time of lock chamber with water, min;

t'_{px} = prepared time of vessel/barge tow/convoy for exit from lock chamber (untie of vessel/barge tow/convoy from bollards on chamber's wall) and time of opening of lower /upper gates in depending on navigable direction, min;

t_{im} = exit time of vessel/barge tow from lock chamber with maneuvers to establish full power of vessel engine(s), min.

The waiting time of vessel/barge tow/convoy in front of ship lock and in lock chamber has been particularly measured. These times do not directly include in total lockage time although they belong to total lockage time.

Total lockage time for 11 ship locks on Upper Danube based on the measures in each ship lock according to the Eq. (3.1) presented in the Table 3.1 depending on the direction of navigation, types of vessel/barge tow and total [3].

Table 2 – Average lockage time across some ship locks on Upper Danube.

Name of ship locks	Average lockage time, min					
	Total	Upstream navigation	Downstream navigation	Pull-towing system	Push-towing system	Self-propelled barge
GEISLING	45.00	63.00	27.00	45.00	-	-
KACHLET	62.33	47.33	77.33	66.20	-	43.00
JOCHENSTEIN	49.80	43.33	59.50	49.80	-	-
ACHACH	45.33	43.66	47.00	45.80	-	43.00
OTTENSHEIM	36.80	43.00	32.66	38.25	-	31.00
ABWINDEN	39.46	47.80	34.25	41.27	34.00	25.00
WALLSEE	44.69	52.00	40.12	46.09	42.00	32.00

YBBS - PERSENBEUG	54.33	73.14	43.28	56.50	42.00	52.00
MELK	40.00	38.25	41.75	41.50	-	38.50
ALTENWORTH	60.69	73.85	45.33	69.57	50.00	50.40
GREIEFENSTEIN	60.00	68.00	52.00	60.00	-	-
TOTAL	48.95	53.94	45.47	50.91	42.00	39.36

The data in Tables 1 and 2, could use for different analyses depending upon research interest. We have considered the ship lock operations for 11 ship locks in row from Geisling (rkm 2354+270) to Greifenstein (rkm 1949+200) in the length of 405 km on Upper Danube in Germany and Austria. In the meantime, new ship locks have been built which don't include in this research.

The preparation of pulled barge tow in front of ship lock and in lock chamber requires more time and more works of ship crew than at push-towing system.

All times such as: enter time of barge tow in lock chamber with preparation for lockage, water filling/discharge of lock chamber, exit time of barge tow from lock chamber/ship lock area are random variables. Obviously, these time periods are under impact of many factors as natural, techno-technological, traffic and others which man cannot control (water levels, waiting time of vessels/barge tows, size of barge tow/convoy, etc.).

4. ANALYSIS OF LOCK OPERATIONS OF SERBIAN LOCK IRON GATE 1

The Serbian and Romanian ship lock Iron Gate 1 (rkm 944+950 – rkm 941+200) are parallel, two ship chambers in row and pair, by alternation changes the direction of lockage each seven days or each the Monday in month at six o'clock. One of them take on vessels/barge tows for downstream direction until second lock take on vessels/barge tows for upstream direction.

As a rule, the both ship locks aren't do if one of them is in capital remount or during serious repairs and different failures. In this case, whole vessel/barge tow flow take on one ship lock in both directions (upstream and downstream).

The data of the Department for lock operation and monitoring of Serbian ship lock refers to only to lock operations without vessel/barge tow operations in lock [6], as shown in Table 3.

Table 3 – Lock operations without vessel/barge tow operations in lock area.

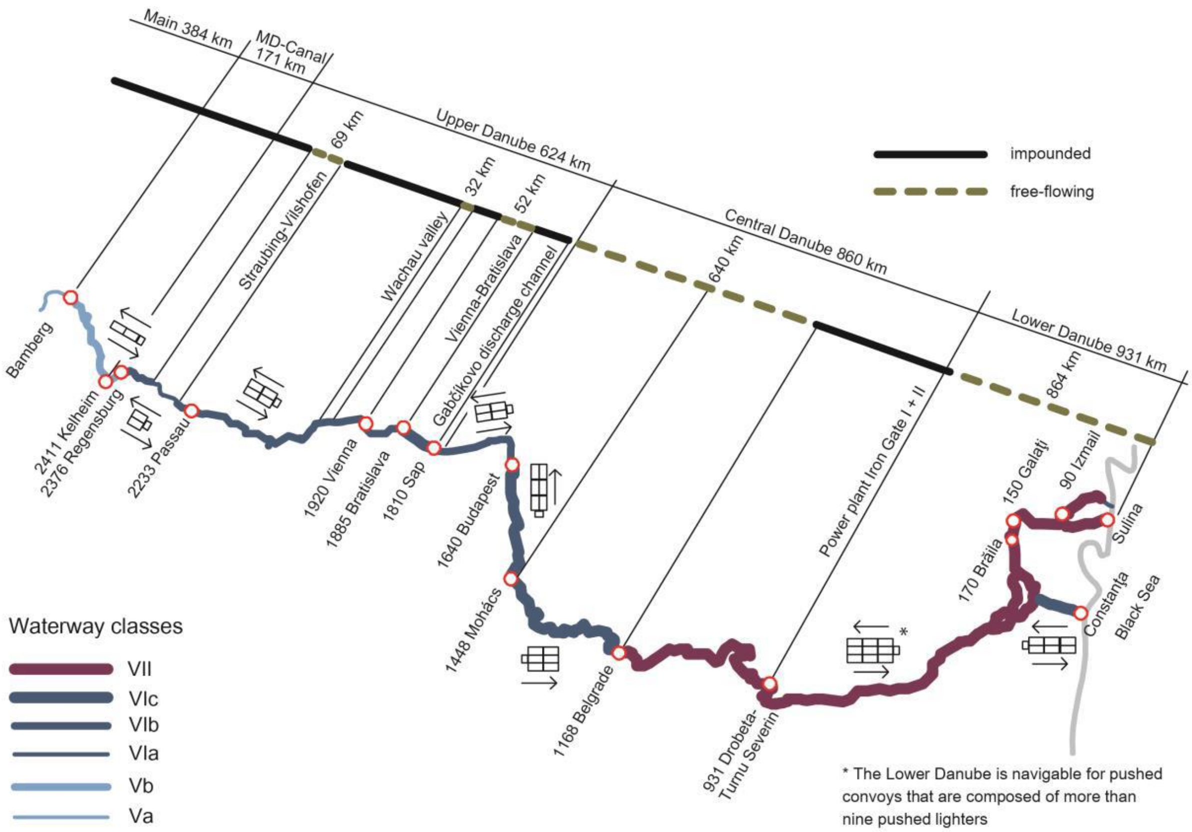
							Time [min]
Enter time of vessel/barge tow/convoy in Serbian lock Iron Gate 1 and connecting vessel/barge tow for bollards on chamber walls							15-30
Opening/closing time	Lower section of double gate on middle head		Working gate on upper head	Plate plugs on upper and lower head	Segment’s plugs on middle head	Double gate on lower head	
	In dropping	In raising	8-10	6	4	12	56-22
	10-12	16					
Filling/discharge time of lock chambers with water (equalizing water levels between lock chambers)							15
Disconnecting time of vessel/barge tow/convoy from chamber’s bollards, transit time of vessel/barge tow in upstream/downstream Chambers and connecting vessel/barge tow/convoy for chamber’s bollards							20-30
Disconnecting time of vessel/barge tow/convoy from							

chamber's bollards and transit time of vessel/barge tow/convoy to lock Berths (in upstream/downstream directions)		20-30
Total		126-165
Total in hours		2.1-2.75

We calculated the total lockage time for vessels/barge tows or convoys from the start of damping ship engine(s) or reduce speed in front of ship lock to the full power of ship engine(s) on the other side of lock in alternations of upstream and downstream navigation. The waiting time of vessel/barge tow at lock anchorages and lock chamber and time of formation of barge tow did not measure in official departments of Iron Gate, although these times are the part of total lockage time.

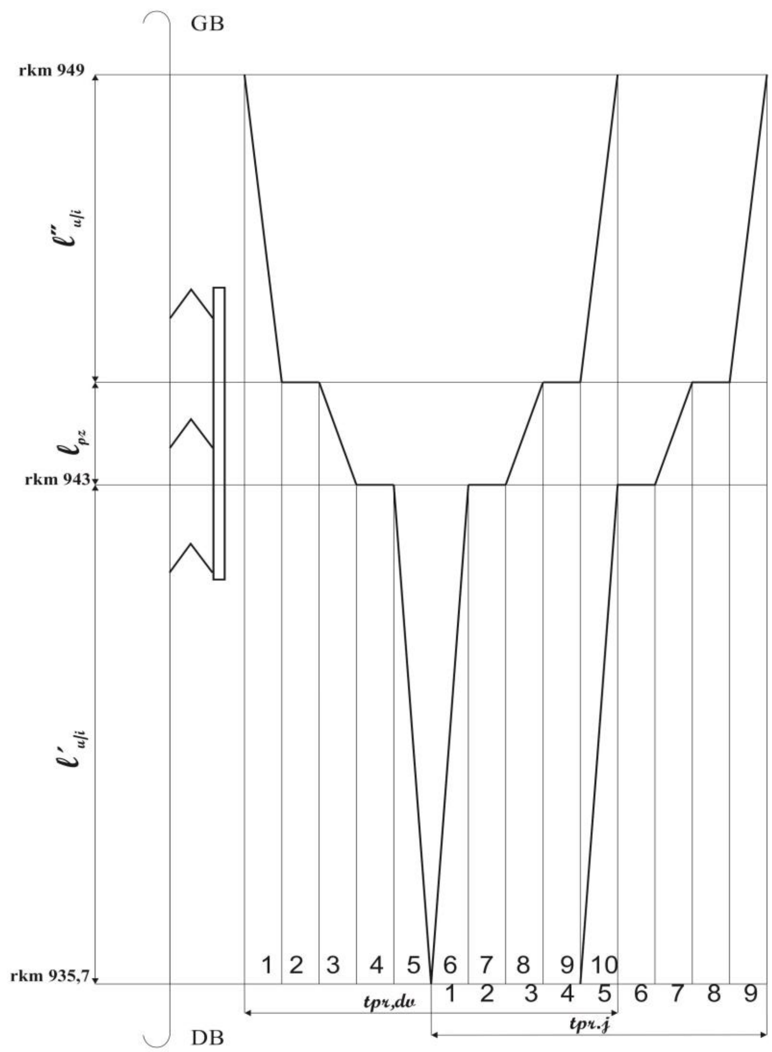
The vessels/barge tows differ according to sizes and structure. It has the impact to the lock capacity and waiting time of vessels/barge tows at lock Iron Gate 1, as shown in Fig. 2.

Figure. 2 – Maximum possible dimensions of barge tow/convoy on the Danube waterway according to UNECE waterway classes (Fairway Rehabilitation and Maintenance Master Plan – Danube and its navigable tributaries, Version 13, November 2014, p.9)



Graphical presentation of upstream and downstream lockage of vessel/barge tow/convoy across Serbian lock Iron Gate 1 was composed by the data of Department for lock operations and monitoring and the sample on lock operations from 2013, as shown in Fig. 3.

Fig. 3 – Graphical presentation of upstream and downstream lockage of vessel/barge tow/convoy across Serbian lock Iron Gate 1 (Radmilović, Maraš, Milović, 2017, p. 14)



Legend:

GB = Upper Basin

DB = Lower Basin

$l'_{u/i}$ = enter/exit distance of vessel/barge tow in lower basin;

$l''_{u/i}$ = enter/exit distance of vessel/barge tow in upper basin;

l_{pr} = transit distance of vessel/barge tow between two chambers (from first to second chamber);

$t_{pr.dv}$ = lockage time in both directions;

$t_{pr.j}$ = lockage time in one direction.

Operations

Two-way lockage

1,6 = enter;

2,4,7 and 9 = technical operations in lock chambers;

3,8 = transit from first to second chamber;

5,10 = exit.

One-way lockage

6,8 = technical operations in lock chamber;

6,8 = transit from first to second chamber;

9 = exit.

Technological diagrams approximately present an average upstream and downstream lockage including particular lock operations for ship lock Iron Gate 1 and particular lockage for vessels/barge tows/convoys, as shown in Figs. 4. and 5.

Figure. 4 – Average downstream lockage time across Serbian lock Iron Gate 1 with two chambers in row (Radmilović, Maraš, Milović, 2017, p.14)

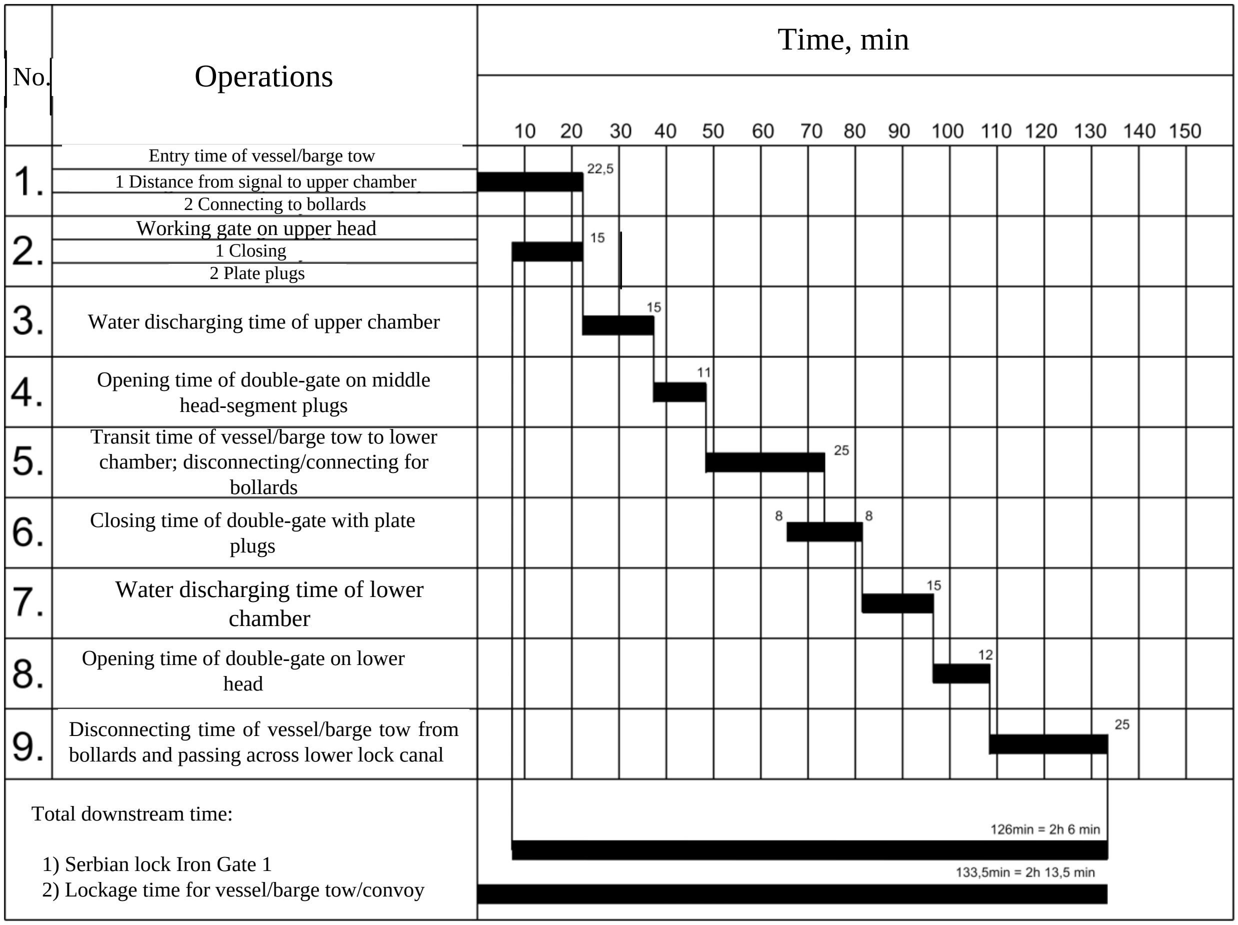
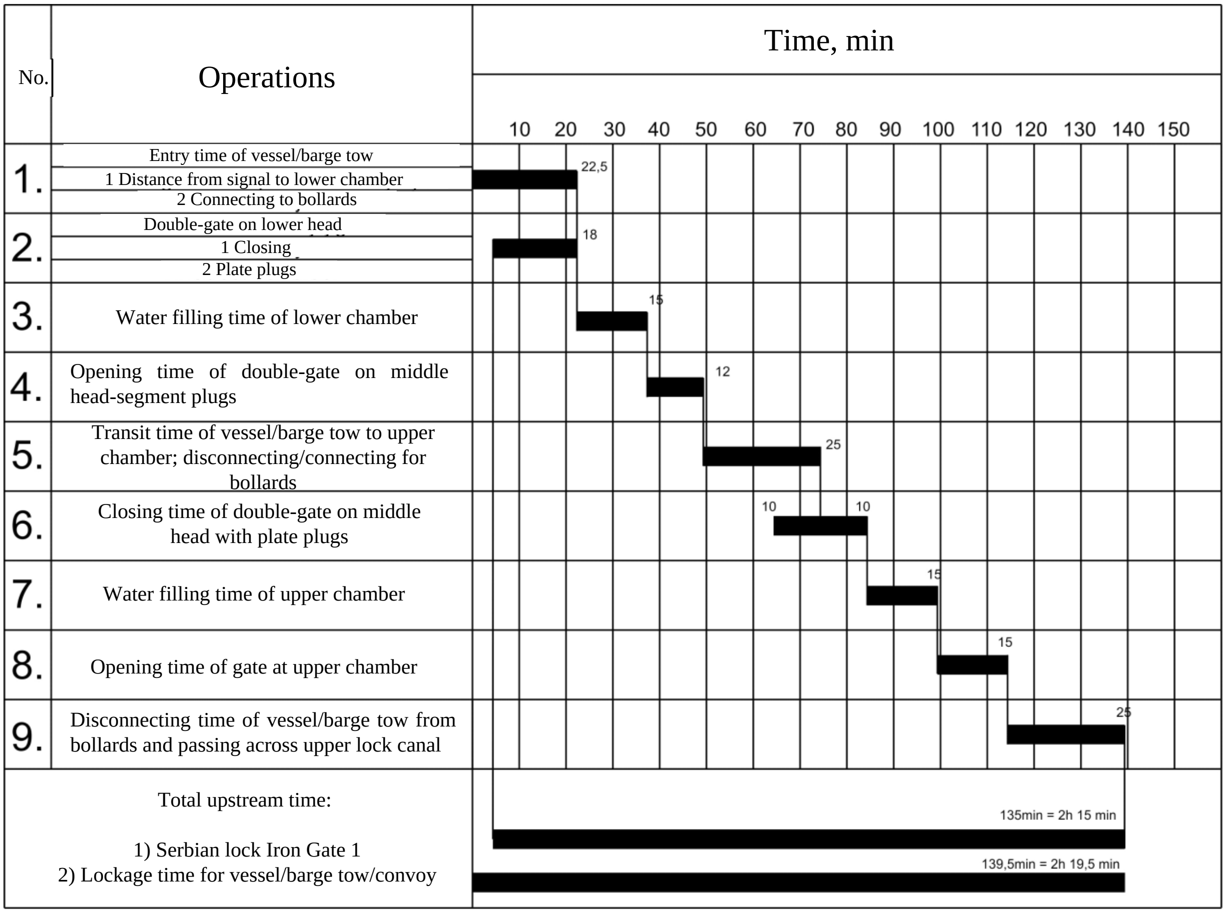


Fig. 5 – Average upstream lockage time across Serbian lock Iron Gate 1 with two chambers in row (Radmilović, Maraš, Milović, 2017, p. 15)



If the duration of a complete lockage cycle (both directions) takes 273 minutes or 4 hours and 33 minutes, average free-flow waiting time is already 45 minutes per vessel assuming a uniform arrival pattern (30 min per vessel in both the busy period and the quiet period od day plus 15 min due to possible congestion).

For instance, 10 620 540 tons of cargo and 7063 vessels have passed across Serbian lock Iron Gate 1 including vessels without cargo (empty vessels) in 2016. These vessels are quite concentrated on certain hours of the day, 70% of the daily passages are concentrated in 12 opening hours, whereas the remaining 30% of the arrivals are distributed over the other 12 hours. This leads to total waiting time due to congestion:

$$0.7 x 7063 x 15/60 = 1236 \text{ hours for 2016,}$$

which can be valuated against on average value of 74 Eur. This study calculated on a value of 78 Eur per vessel per hour for container shipments and 74 Eur for non-container shipments [7]. It means the waiting time costs in 2016 for Serbian lock Iron Gate 1 thus amount to

$$1236 x 74 = 91464 \text{ Eur per year.}$$

The weakness of this method is in the valuation which does not take into account the composition of the types of vessels/barge tows, although the share of large vessels is much higher than small vessels [6].

Based on the analysis of lock operations in both locks Iron Gate 1 (Serbian and Romanian)

through number of lockages, number of vessels across locks, freight tons of locked vessels andcargo throughput across locks Iron Gate 1 from 1970-2016, the results are following:

SERBIAN LOCK IRON GATE 1

- Average number of vessels per one lockage ………………………. 5 vessels
- Participation of freight tons in cargo tons ………………………… 48.75%
- Average amount of cargo per one lockage ………………………… 6180 tons
- Average amount of cargo per one locked vessel …………………… 1236 tons
- Usage of permitted water area of lock chamber per one lockage ….. 37%

ROMANIAN LOCK IRON GATE 1

- Average number of vessels per one lockage …………………………… 5 vessels
- Participation of freight tons in cargo tons ……………………………… 51%
- Average amount of cargo per one lockage ……………………………… 5991 tons
- Average amount of cargo per one locked vessel …………………………1198 tons
- Usage of permitted water area of lock chamber per one lockage ……….. 37%

COMMON WORK OF BOTH SHIP LOCKS IRON GATE 1 (SERBIAN/ROMANIAN)

- Average number of vessels per one lockage ………………………………. 5 vessels
- Participation of freight tons in cargo tons ………………………………… 49.85%
- Average amount of cargo per one lockage ………………………………… 6086 tons
- Average amount of cargo per one locked vessel ………………………….. 1217 tons
- Usage of permitted water area of lock chamber per one lockage ………… 37%.

The estimation of participation of empty vessels according to the total number of locked vessels changes between 30% and 40%.

The evidence of stoppages of Serbian lock Iron Gate 1 in period from 2010 to 2019. shows that the Serbian lock had longer periods without work.

In this period the Serbian lock Iron Gate 1 has worked 242 average days and the out of function 124 days per year. Main cause is old age of equipment and facilities of lock resulting in high maintenance and operation costs [6]

5. COST OF LOCKAGE IN SERBIAN LOCK IRON GATE 1

This cost includes following items: maintenance cost (current and capital maintenance, repairs, rehabilitation and others according to the specifications) and operation cost (consumption of electrical energy in Serbian lock through consumed amount of water in MWh; consumed electrical energy in work of lock equipment in MWh and gross salaries of workers) in time period from 2013 to 2016. [6]

The structure of employees in the Department for lock operations and monitoring of Serbian lock is following:

- Deputy of Director for exploitation of hydro power station and lock Iron Gate 1.
- Lockmaster into the shifts.
- Electricians into the shifts.
- Experts for hydraulics into the shifts.

The Department for maintenance charges to current and investment maintenance of lock.

According to the Technical Sector of Hydroelectric power station the maintenance cost increases with degree of 15% per year and operation costs with degree of 5% per year because of old age equipment and lock (47 years) [6].

Based on the statistical analysis of average price of lockage in Serbian lock, the price has approximately determined for period from 2013 to 2016. In this calculation two alternatives have been developed. In first alternative the maintenance and operation costs did not include investment costs until second alternative encompasses the costs as whole (maintenance, operation and investment costs):

- First alternative – average price of lockage across Serbian lock Iron Gate 1 and standard deviation:

  $T_{sr.pr}$ = 479.18 Eur per one lockage for considered period 2013-2016.

  S = 306.66 Eur per one lockage.

- Second alternative – average price of lockage across Serbian lock Iron Gate 1 and standard deviation:

  $T_{sr.pr}$ = 806.21 Eur per one lockage for considered period 2013-2016.

  S = 476.80 Eur per one lockage.

These results could conditionally receive since the pattern is restrict in time period (very short) and maintenance cost have had large deviations from 582 000 Eur and 703 lockages in 2013 to 104 000 Eur and 1644 lockages in 2014. [6].

Addition costs mainly depend on the duration of adaptation and rehabilitation of Serbian lock. In this period vessel's traffic in both directions will be accepted by Romanian lock Iron Gate 1. Average number of lockages for both locks is approximately 3250 lockages per year from 1970 to 2016 year. In former work the Serbian lock have had largest number of lockages in 1973 (3102) and Romanian lock in 1970 (4230). By the survey of number of lockages could see that this number decreases and each lock could receive whole vessel's traffic in both directions, for example, one of them in capital remount.

The addition cost could determine when Romanian lock only works by same methodology. For example, 21 562 315 tons of cargo and 14 248 vessels have been passed across Romanian lock Iron Gate 1 including empty vessels in 2016. If the duration of a complete lockage cycle in both directions takes 273 minutes or 4 hours and 33 minutes (Fig. 4. and 5) same as in Serbian lock Iron Gate 1, average free-flow waiting time for both directions could approximately assume 70 minutes per vessel from which 25 minutes due to congestion.

Under same assumptions, these vessels are quite concentrated on certain hours of the day, 70% of the daily passages are concentrated in 12 opening hours, whereas the remaining 30% of the arrivals are distributed over the other 12 hours. This lead to total waiting time due to congestion:

$$0.7 \times 14248 \times 25/60 = 4156 \text{ hours per year,}$$

which can be valuated against on average value of 74 Eur per vessel-hour for non-container shipments [7]. It means the waiting time costs in 2016 during the adaptation of Serbian lock Iron Gate 1 are following:

$$4156 \times 74 = 307\,544 \text{ Eur per year,}$$

or 300-320 thousands Eur, if the adaptation lasts one year.

6. ECONOMIC ANALYSIS: SAVINGS AFTER RESTORATION OF SERBIAN LOCK IRON GATE 1

The savings refer to:

- Saving in trip time or voyage time of vessels
- Saving in operative costs of shipping companies.

Based on available data the saving in trip time of vessel should determine after the adaptation of Serbian lock. According to official data of Technical Sector of Serbian part of Iron Gate 1 did not exist difference between upstream and downstream lockage time. Their estimations of average lockage time in one direction is 100 minutes only for lock operations in conditions before the adaptation. By the adaptation of Serbian lock Iron Gate 1 the lockage time decreases and returns on 90 minutes. This will have the impact on lock capacity and number of lock stoppages.

For 46 years the Serbian lock have had 1646 average number of lockages per year (maximum 3102 lockages in 1973 and minimum 207 lockages in 1995) and the Romanian lock have had 1639 average number of lockages per year (maximum 4230 in 1970 and minimum 244 lockages in 1999).

The saving in trip time of vessel could simply determine on annual level for average number of lockages per year and average saving time at one lockage (upstream or downstream) for vessel in Serbian lock as [5]:

1646 lockages x (100 – 90 minutes) = 16460 minutes or 274.33 hours or 11.43 days.

The calculated savings are incomplete and rough estimations since the calculation don't include many and complex variables such as: duration of lockage time for most often types of

vessels/barge tows, annual opening hours of lock, uneven arrivals of vessel/barge tow at Iron Gate 1, priority of service, etc.

According to the number of locked vessels in the period 1970-2016, average number of locked vessels per year is 8500 vessels including empty vessels in both directions in Serbian lock.

Average free-flow waiting time for both directions approximately assumed 45 minutes per vessel (30 minutes per vessel in both the busy and quiet period of day and 15 min due to possible congestion). After adaptation of Serbian lock the average free-flow waiting time of vessels for both directions approximately assumed 25 minutes per vessel (15 minutes per vessel in both directions and 10 minutes per vessel due to possible congestion). The assumption is that these vessels quite concentrated on certain hours of the day, 70% of daily passages are concentrated in 12 opening hours, whereas the remaining 30% in other 12 hours. This leads to total waiting time of vessels due to congestion:

- Before adaptation of Serbian lock:

  0.7 x 8500 x 15/60 = 1487.5 hours per year

- After adaptation of Serbian lock:

  0.7 x 8500 x 10/60 = 991.66 hours per year.

Now, average cost of vessel waiting time per lockage by average price of 74 Eur per vessel-hour for non-container shipments:

- Before adaptation of Serbian lock:

  1487.5 vessel-hours/year x 74 Euro/vessel-hour = 110 075 Eur/ year

- After adaptation of Serbian lock:

  991.66 vessel-hours/year x 74 Eur/vessel-hour = 73 383 Eur/year, and

- Cost saving for shipping companies:

  110 075 – 73 383 = 36 692 Eur/year.

7. EVALUATION OF AIR POLLUTION AND NOISE IN AREA OF SERBIAN LOCK IRON GATE 1 AFTER ADAPTATION

Environmental cost at the Serbian lock Iron Gate 1 comes from the damages producing vessel emissions in air, water and soil. The Serbian lock area includes the space in the length of 14 km alongside Danube fairway, from rkm 949 (position of first traffic signal for entrance of downstream vessels/barge tows in Serbian lock area) to rkm 935+700 (position of first traffic signal for entrance of upstream vessels/barge tows in Serbian lock area).

Air pollution refers to the emissions of polluters from vessel engine(s) such as: CO_2 (carbon dioxide, NO_x (nitrogen oxides), SO_x (sulfur o0xides), $PM_{x,y}$ (particulate matters, diameter from x to y) and NMVOC (Non-methan volatile organic compounds). Their emissions mainly depend on the kind of fuel which use the Danube vessels. Most frequent fuel on Danube vessels is diesel oil. For this type of fuel, the air pollution will be evaluated within Serbian lock area in length of 14 km and average locked vessels per year of 8500 vessels in period 1970-2016.

We assumed that one quarter of 8500 vessels are motor vessels such as: pushboats, pulltugs, self-propelled barges, passenger ships including cruise ships and recreational boats and yachts having in mind that average number of vessels per on lockage equals to 5 (Section 4.).

Main and auxiliary vessel engine(s) are medium- and high-speed diesel motors with following characteristics: different old age, different powers, different outfitting and fuel consumption. The fuel consumption depends upon engine power, production year of engine, number of kilometers in navigation, usage of carrying capacity, size of barge tow, etc. Empty barge tows have less fuel consumption and emissions also.

The determination of emissions is connected by average power of main engines, specific type of diesel fuel (ship diesel oil with low sulfur content to a maximum of 10 ppm) and average diesel fuel consumption per kg/vessel-km. Average fuel consumption of diesel oil has been established of 38.63 l/vessel-km by comprehensive analysis and working evidence in sample of pushboats (nominal power from 360 kW to 2100 kW) with push barges, cargo motor vessels or self-propelled barges (nominal power between 600kW and 1300 kW) which passed across Serbian lock Iron Gate 1 during 2013.

As mentioned, we assumed that one quarter of total number of locked vessels are motor vessels. It means from total number of locked vessels per year of 8500 vessels 2125 vessels have been motor vessels.

Average fuel consumption in Serbian lock area in length of 14 km is following:

38.63 l/vessel-km x 14 km = 540.82 l/vessel.

Now, total fuel consumption in Serbian lock area is following:

2125 vessel/year x 540.82 l/vessel = 1 149 242 l/year [6].

The actual engine power and diesel fuel consumption per kg/vessel-km for all types of the Danube vessels are not precisely known since precise and comprehensive data on the engine composition of Danube fleet are not registered on the Danube Region level. For these reasons, the bottom-up approach has been applied to local inventories based on the interviews with ship owners and by means of consistency check with fleet registers by the Authority for Determination of the Seaworthiness in Serbia [8].

The EMEP/EEA (European Monitoring and Evaluation Programme/European Environment Agency) air pollutant inventory guidebook and more precisely the International navigation, national navigation, national fishing and military (shipping) [9], were considered as reference for emission estimate at inland navigation across Serbian lock Iron Gate 1.

Emissions from inland navigation across Serbian lock could be estimated at different levels of complexity. In paper [9 pp. 12-29], are expressed three tiers of increasing complexity as: " 'Tier 1' method using default emission factors only, 'Tier 1' emission factors assume an average technology for fleet." This approach for navigation uses the general equation to be applied for the different NFR (Nomenclature for Reporting Source Category Code) codes [9 p. 12]:

$$E_i = \sum_m \left(FC_m \cdot EF_{im}\right) \qquad \ldots (7.1)$$

where

E_i = emission of pollutant *i* in kilograms;

FC_m = mass of fuel type *m* sold in the country for navigation (tons);

$EF_{i,m}$ = fuel consumption – specific emission factor of pollutant *i* and fuel type *m* (kg/tons);

m = fuel type (bunker fuel oil, marine diesel oil, marine gas oil, gasoline).

The applied factors for calculation of emissions from inland navigation at Serbian lock have

adopted by European Environment Agency. They presented in Table 4.

Table 4 – Emission factors for vessels using diesel oil.

Emission factor for vessels using diesel oil as propulsion fuel		
Polluter	**Emission factor**	**Unit**
CO_2	3200	kg/t goriva

NO_X	79.3	kg/t goriva
PM_{10}	1.5	kg/t goriva
SO_2	0.2 S	kg/t goriva
NMVOC	2.8	kg/t goriva

S = percentage sulfur content in fuel: 0.1% from 1 January 2010 for inland waterway vessels and ships at berth in Community ports.

Based on the data on emission factors (Table 4) and Eq. (7.1) evaluated amount of pollutants' emissions presented in Table 5.

Table 5 – Annual emissions of air polluters from vessels in Serbian lock Iron Gate 1 area.

Polluter	Emission factor, kg/t diesel fuel	Correction factor	Total amount, tons
CO_2 – carbon dioxide	3170	1000	3643
NO_x – nitrogen oxides	78.5	1000	92.21
PM_{10} – particle matters with diameter of 10 microns	1.5	1000	1.72
SO2 – sulfur dioxide	0.0002	1000	0.000229
VOC – Volatile organic compaunds	2.7	1000	3.1
Total amount			3740.03

The estimation of ecological efficiency for inland navigation system at Serbian lock area and the process of measure of carbon footprint mainly depend upon gather data. In this case gathering data don't exist that we have to receive this evaluation as very crude estimation in view of precisely.

The basis of this calculation can be found on the TREMOVE data. The TREMOVE model is a policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector. The model covers passenger and freight transport and covers the period 1995-2030. TREMOVE distinguishes 21 types of inland waterway transport vessels, namely 3 types of vessels (cargo, tanker and pusher) and 7 sizes (from under 250 ton until over 3000 ton). Air pollution costs from vessel emissions presented in Table 6 for most common types of vessels [7].

Table 6 – Emission costs for most common types of vessels (Eur per vessel-kilometers).

Type of vessel	Rural area				Urban area (300000 inhabitants)			
	SO_2	NO_X	PM	VOC	SO_2	NO_X	PM	VOC
Dry cargo,400-650 t	0.03	0.34	0.07	0.01	0.09	0.34	0.49	0.01
Dry cargo,1500-3000 t	0.09	1.28	0.28	0.03	0.31	1.28	1.98	0.03
Tanker, 450-600 t	0.02	0.34	0.06	0.01	0.08	0.34	0.46	0.01
Tanker, 1500-3000 t	0.14	1.98	0,45	0.05	0.49	1.98	3.16	0.05
Push barge, 400-650 t	0.12	1.67	0.36	0.04	0.43	1.67	2.51	0.04
Push barge, 1500-3000 t	0.12	1.67	0.36	0.04	0.42	1.67	2.58	0.04

Based on the emission costs for tanker (1500-3000 t) we calculated annual total cost of emissions in Serbian lock area as rural area, as shown in Table 7.

Table 7 – Annual emission costs from vessels in Serbian lock area.

Polluters	Total amount, tons	Annual vessel-km	Costs, EUR/t	Cost EUR/vessel-km	Total, EUR
CO_2	3643		87.00		316 941
NO_x		29750		1.98	58 905
PM_{10}		29750		0.45	13 387.5
SO_2		29750		0.14	4 165
VOC		29750		0.005	1 487.5
Total					394 886

Under an assumption that 2125 motor vessels passed across Serbian lock area in length of 14 km, it means these vessels achieved:

2125 motor vessels x 14 km = 29750 km per year [6].

The CO_2 emission factor for diesel oil fuel has been taken by the Report of German refineries [10]. The calculation yields CO_2 emission factor of 3170 kgCO_2/ton fuel (pushers, pull boats and freight motor vessels and 2995 kgCO_2/ton fuel (cruise passenger ships).

The valuation of CO_2 emissions was adopted by the literature [11]. Extrapolating the cost values back to 2011 prices, results of 87 Eur per ton CO_2, which is the most recent estimate for all EU countries for period to 2020.

The noise with low frequency, such as in the Danube navigation at hydropower of Iron Gate 1, is low in comparison with noise producing road traffic in City of Kladovo and their surroundings. The City of Kladovo with surroundings has about 20000 inhabitants, only the Kladovo about 9000 inhabitants. The urban part of Kladovo get away about 10 km from hydropower Iron Gate 1 with ship locks. The determination of total costs of noise in/out borders of Kladovo must be connect with number of inhabitants under the impact of noise. This depends on level of urbanization in Kladovo area. We will assume that inland navigation in area of ship locks produces low cost of noise, since few peoples live alongside of Danube banks in this case.

8. CONCLUSIONS

There is no straightforward answers to the question about the decision support factors and best adaption measures to face the impacts of low water periods on the Danube waterway transport (DWT). However, the behavior of the actors in the DWT market suggests that customers are the ones under more pressure to adapt, particularly Danube shipping companies (and ship owners). Noticeable impacts are expected to occur on the Danube hydrological regime due to changes on water discharge, changes on river morphology and water temperature. Changes on Danube water discharges show direct consequences on efficiency, safety and reliability of Danube waterway transport. High discharges will cause traffic problems and low water discharges will limit loading capacity and will increase grounding risk.

The level of urgency for adapting differs between Danube shipping companies, shippers and forwarders, with one side, and the official institutions for management and maintenance of Danube fairway, with second side. The adaption strategies and measures could be: strategy of new Danube vessels' design, logistics measures and Danube infrastructural strategies for maintenance of fairway and river management, including Serbian and Romanian locks Iron Gate 1.

The Danube shipping companies adapt on different ways as follows:

- Waiting time of higher water levels
- Lightering/reloading of cargo from vessels to minimize its draft

- Changes of number of barges in barge tows or train if it is necessary
- Restricted carrying capacity of vessels/barges.

All these measures have the impact on lock operations of the Iron Gate 1. These cases, especially longer periods of low water levels could decrease the number of locked vessels in both directions in future, since the vessels/barge tows passing across locks sail on average distance of 800 km. Nearest critical upstream place at Danube fairway from Iron Gate 1 is on rkm 1195, approximately 146 km from Iron Gate 1 and downstream on rkm 823, approximately 112 km from Iron Gate 1 and 40 km from Iron Gate 2.

The project of restoration and adaption of Iron Gates 1 understand high level of quality of lockages in both directions, savings in operation and maintenance costs, cost savings for shipping companies, increasing of reliability and safety of inland navigation with less stoppages and vessel waiting times at locks and lock chamber.

References:

[1] Via Donau. Manual on Danube Ports. Vienna: Via Donau – Entwicklungsgesellschaft mbH fur Telematik und Donauschiffahrt; 2003.

[2] ICPDR – International commission for the Protection of the Danube River. Sediment management in the Danube River Basin. Vienna: 2013, www.danubeparks.org

[3] Radmilović Z. Inland waterway transport (in Serbian). Belgrade: University of Belgrade, Faculty of Transport and Traffic Engineering; 2007.

[4] Radmilović Z, Maraš V, Jovanović S. Ship Lock as general queueing system with batch arrivals and batch service. Scientific Journal on Traffic and Transportation Research 2007; Vol. 19, 6: 343-351.

[5] Radmilović Z, Maraš V Role of Danube inland navigation in Europe International Journal for Traffic and Transport Engineering 2011; Vol. 1, 1: 28-40.

[6] Radmilović Z, Maraš V, Milović K. Feasibility Study of Adaptation of Ship Lock Iron Gate 1, Part of Transport (in Serbian). Belgrade: 2017.

[7] ECORYS Transport and METTLE. Charging and pricing in the area of inland waterways – Practical guideline for realistic transport pricing, Rotterdam: Final report, European Commission – DG TREN. 2005.

[8] Tomić-Petrović N, Radmilović Z, Rajković R. Environmental status of the Danube commercial navigation: Serbia and the Danube border countries, Journal of Marine Engineering and Technology, paper accepted for publishing, 2019.

[9] Trozzi C, De Lauretis R., International navigation, nautical navigation, national fishing, military (shipping), EMEP/EEA air pollutant inventory guide book: 1.A.3.d.i, 1.A.3.d.ii, 1.A.4.c.ii. European Environment Agency. Copenhagen: 2013.

[10] Juhrich K. CO_2 Emission Factors for Fossil Fuels, Climate Change, German Environment Agency (UBA), June 28/2016.

[11] Kuik O, Brander L, Tol R.S.J. Marginal abatement costs of greenhouse gas emissions: A meta analysis, Energy Policy 2009;, Vol. 37, 4: 1395-1403, Elsevier Ltd.