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Performance measurement of the port logistics system

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Abstract: Water transport has an overwhelming contribution to international trade. Between 80% and 90% of commodity trading are carried out by means of maritime transport and inland waterway transport. Under these circumstances, the port acts as logistical centre which is crossed each year by major commodity flows. Based on these aspects, the research carried out was aimed to determine a set of parameters in order to facilitate the assessment of the performance of port services provided to ships and goods. The authors suggest a set of specific parameters. These parameters need to improve performance of berths operations, especially productivity, by substantially increasing traffic by using facilities, existing human and material resources, possibly with some small-scale investments. Port performance parameters were structured as follows: production parameters, service parameters, resource use parameters and productivity parameters. The research methodology will be used further to assess these indicators and integrate them into a comparative study of the Black Sea ports.

Key words: port performance, port output, port productivity

1. Introduction – The need to use a port performance parameters system

Over the past few years ports have become logistic hubs which provides complex services to both ships and goods. In this regard, the measurement and analysis of performance in port activities is necessary, so stakeholders can know to what extent they improve or, on the contrary, worsen the services they provide to their customers. Studies and research undertaken in this field of activity determine the measures and actions needed to be taken in medium to long term in order to use as efficiently as possible the facilities and resources that ports have at their disposal to provide high quality services.

The results obtained are accessed both in the planning process of existing port activities as well as in the identification, development and solutions implementing for qualitative and / or quantitative improvements of the use of port resources [3, 7, 21, 24].

From a different perspective, the port performance analysis provides the opportunity of performing comparative studies between ports, in such way that it is possible to identify the necessary policies and measures proposed by port management to improve their business [2, 4, 9].

If the necessary information in respect of port activities is not collected, analyzed and distributed, there will be no possibility of determining what needs to be improved and what measures should be taken to increase the performance of these activities. Literature review reveals that performance indicators can be tracked continuously or punctually depending on the purpose for which they are used [8, 11, 19].

Subject of the paper is a sequel of the research initiated towards identifying the port development priorities in the Black Sea basin, which pointed out the need to carry out an analysis of the overall operating framework for ports in this area and reporting port facilities and performance to a set of Priority Indicators for Port Development (PIPD) [14]. Research conducted in the assessment of port logistics performance shows that the parameters that are continually being monitored are used inside the port and refer to it as a singular, isolated entity. Ducruet C. (2016) and Mangan J. et al. (2016) [6, 13] show that when the parameters are continuously monitored, they are in fact the normalized parameters of the port activity and their values become own standards of that port.

Wiegmans B. and Dekker S. (2016) claims that punctual parameters are in the form of information which describes port performance at a given time, which is used to decide where there is an abnormal port activity [25].

Basis the above, a correct assessment of the activity of a port can be performed when all factors influencing this activity are considered.

Port performance indicators must consider these factors and reflect the following: the way port facilities and resources are used to emphasize the effect of corrective actions in order to prevent losses or improve business [12, 17]; the way intensive activity factors are assessed so that planners can decide when and where additional resources are required [20]; the quality of services offered to shippers, carriers and other port users [16, 23]. Thus, the research carried out in this paper was oriented towards determining a set of indicators used to facilitate the assessment of the performance of port services provided to ships and goods.

Further, the authors propose a set of specific indicators, which were based in accordance with the particularities of the port activities carried out in the main ports of the Black Sea basin (Constanta, Odessa, Ilicins, Varna, Burgos, Trabzon, Poti, Batumi, Novorossiysk).

Although other research address port-performance issues, the experience and practices specific to Eastern European ports requires a specific approach to these concerns [21, 22]. The authors consider that a set of port performance parameters should provide an overview of the achievements associated with a homogeneous group of berths based on a series of data that needs to be collected continuously. Such parameters need to improve performance of berths operations, especially productivity, by substantially increasing traffic by using facilities, existing human and material resources, possibly with some small-scale investments.

Port performance parameters were structured as follows: production indicators, service indicators, resource use indicators and productivity indicators. The research methodology will be used further to assess these indicators and integrate them into a comparative study of the Black Sea ports.

2. Production parameters

Production is defined, in a broader sense, as the amount of work done, or the quantity of goods produced over a reference time. With reference to port activity, production represents the amount of freight, expressed in tones, handled in a fixed time unit. The average quantity of cargo handled at berth (C_m, tons). For the operations at berths, the average production of a berth is defined as the total quantity of cargo handled by all ships (including barges etc.) moored at analyzed berth (or group of berths taken into consideration), with its own resources, in a reference period, divided by the number of berths:

$$C_{m_{berth}} = \frac{\sum C_{m_i}}{N_{berth}} \quad (tons)$$

where: $C_{m_{berth}}$- the average amount of cargo handled at berths in the group; C_{m_i}- the average amount of cargo handled at berth i; N_{berth} - number of berths in the group.

In most cases, handling operations require the measurement of this parameter through a unit of measure (cbm, TEU, piece etc.). To be able to correlate with other parameters in order to be able to aggregate at port level with other wider categories of goods or type of operations (import and export, storage etc.), it is necessary that the average quantity cargo handled at berth C_{m_i} to be expressed in tones. From the theoretical point of view, measuring the quantity of manipulated goods does not seem to pose any problems. Further, some examples from port practice that show that such analysis is much more complex are presented.

The first example is that of the amount of cargo that can be handled several times during loading or discharging operations. Another case that poses problems is that the goods are only shifted either to have access to another cargo or to be rearranged in a pre-loading stage so that it can later be manipulated more easily. Another issue is related to the way in which is registered the amount of cargo handled at a berth from a vessel which is moored at two berths so that part of the cargo is handled on a berth and another part is manipulated by an adjoining berth.

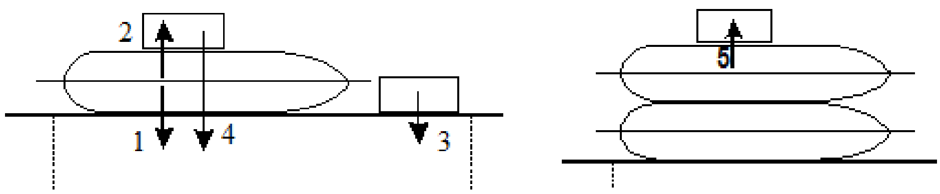

Figure 1. The amount of cargo included in the berth transfer capacity

In order to be sure that the data was recorded correctly, without being recorded multiple times, the following convention is required.

The amount of cargo handled at berth (figure 1) will be given by the formula:

$$C_{m_i} = 1 + 2 + 3 + 4$$

where: 1 - the amount of cargo handled (loaded or unloaded) directly between vessel and berth; 2 - the amount of cargo handled between vessel and inland waterway transport units or feeders which are moored near the vessel; 3 - the amount of cargo handled between inland waterway transport units and berth; 4 – the amount of cargo handled between vessels moored in double berth and berth.

The amount of cargo handled by vessels of any kind moored in a double berth if it is not transferred to the berth will be excluded because it is not a measure of use of resources existing at subject berth (5).

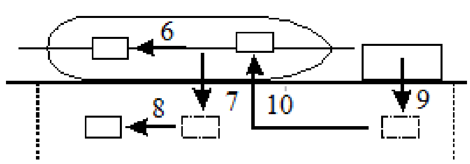

Figure 2. The amount of cargo included in the transfer capacity of the berth

Comments resulting from the discussions with port operators' representatives led to an additional set of rules, plotted in Figure 2.

Therefore, in order to include the goods operated by berth manipulation or inside the vessel's stores, which actually represents the handling of the same quantity of cargo twice, using the resources provided by the respective berth, an additional set of rules correspond to the following situations:

- Adding to the quantity of cargo handled at the berth to the quantities of cargo moved inside the vessel (inside the same store or between different stores) even if it is not discharged (6);

- Adding double the amount of cargo unloaded or loaded, using the berth, from seagoing vessels or inland waterway vessels berthed (including double berthed vessels) if they were subsequently shifted to berth (because this quantity of was manipulated twice) (7 + 8);

- Including double quantities of cargo handled from one ship to another (including those moored in a double berth) if they were handled using the berth (because this cargo was also handled twice: once from the sea vessel or from the inland waterway vessel to quay and then from quay to another vessel) (9 + 10).

Conclusion 1: To determine the average quantity of cargo handled by a berth, must be included any quantity of cargo handled by using existing resources of subject berth.

Conclusion 2: To determine the average quantity of cargo handled by a berth the following must be excluded: cargo handled from a vessel moored at a double berth, cargo handled from vessels or inland waterway vessels if such handling was done with other resources or without the cargo being transferred to berth (e.g. goods transferred by floating crane to a ship or barge in a double berth).

The mooring berth group must be adjacent (and therefore constitute an operating front) and have similar characteristics (for example, general cargo berths, ore, container etc. but not a combination thereof).

In addition to this main parameter, the following parameter are also used in practice:

- the average quantity of cargo handled per meter of quay calculated by dividing the total quantity of cargo handled during the considered period to the length of the quay (t / m);

$$C_{sm_{berth}} = \frac{\sum C_{m_i}}{L_{berth}} \quad (tons/m)$$

where: $C_{sm_{berth}}$ - the average specific quantity of cargo handled at the mooring berths in the group; $\sum C_{m_i}$- the amount of cargo handled by the berth i; L_{berth} - the length of mooring berths in the group (m).

This parameter allows pertinent comparisons to be made between the production rates of similar berths (of the same terminal or terminals of the same type) since the berth is a conventional unit whose length depends on the depth of water at berth.

- the extent of use of the berth (%) which represents the ratio between the sum of the berthed vessels LOA (length overall) and the sum of the lengths of berths considered for each vessel in determining the quantity of cargo handled.

$$g_{ub} = \frac{\sum L_{ships}}{\sum L_{berth}} \cdot 100 \quad (\%)$$

where: $\sum L_{ships}$ – sum of length overall (LOA) of all vessels which were operated at the berth or group of berths considered during the period for which the quantity of cargo handled is determined (usually this indicator is determined annually); $\sum L_{berth}$ - the sum of the lengths of berths taken into account, for each vessel operated at berth, in determining the quantity of cargo handled.

The continuous monitoring of this parameter allows it to determine whether the changes occurring in the average length of the vessels are so significant that they must be taken into account in future port development projects through a new assessment of the berth lengths or whether it is advisable to divide the total length of berths for the subject group of berths (in the extreme case of just one berth) in a different number of berths than the existing one.

Port traffic is the amount of cargo transferred through a berth, a group of berths or by a terminal, by different port operators or by the whole port in a given time unit. Berth traffic shall be defined as the total cargo transferred through a berth (or the group of berths which are analyzed) over a determined period, divided by the number of berths. Berth traffic is therefore the total quantity of goods handled, excluding extra manipulation, and includes cargo transferred from double berthed vessels to water and those handled by other means, in other words all cargo which was transferred out berth, in any direction and from/ to any type of vessel.

The terminal traffic is determined by considering all berths of one terminal, and the traffic of the port operator is determined by cumulating the traffic of their berths. Port traffic derives from the centralization of traffic through all port berths.

Traffic is measured in tones and is determined monthly and annually (in the latter case, the references will be made to the annual traffic of the berth, terminal etc.). In the case of other units of measurement, they must be converted into tones, reference being made also to derived units (for example TEU for containers, cubic meters (cbm) for timber, number of heads for livestock etc.). To be significant, berth traffic must be monitored by type of operation (export, import, transit), by commodities with similar features (packing, stowage factor, other characteristics of the goods etc.) which requires the same handling technologies, or depending on the specialization of the berth or terminal.

Port traffic is typically determined annually by type of operation and group of cargoes and is of more strategic importance with the purpose of emphasizing the trend of transfer of cargoes through that port. It must be analyzed in the economic, commercial and socio-political context of port activity, reflecting the influence of these factors on port activities and future trends in port traffic rather than port performance itself.

As in the case of the quantity of goods handled, it is possible to define as a derived parameter the traffic per meter of berth, representing the specific traffic calculated by dividing the traffic categories previously defined by the length of the berth / berths considered.

3. Services parameters

The quality of port services is an important criterion for port competitiveness. Although the measurement of the quality of port services to its users (shipowners, port operators, shippers, etc.) can be achieved through several parameters, it can be considered that the most important is the one that refers to the total residence time of a vessel in port [15].

Starting from the importance that the total residence time of a vessel in port (T_{port}) has on dividing the quality of port services and the total cost of transport, the parameter was detailed in the following components: waiting time until operation (T_{wo}), stationing time at berth (T_{berth}), ship service time (T_{serv}), stationing time in port after operation (T_{ao}), total waiting time in port (T_w).

Port practice emphasize that, in order to be meaningful, the above-mentioned components must be determined by type and group of cargoes, by groups of berths or by their specialization and possibly by type of vessel.

The average stationing time parameters, even if are determined under the conditions presented above, they provide only general overview of how the analyzed port operates. From the port's point of view, the ratios which are established between these parameters are more relevant and can give indications regarding the way the time of a vessel in port is used. For example, an important parameter is the ratio between the average service time and the total residence time of a vessel in port; it should have values as close as 100% and a low value indicates a poor port efficiency or excessive occupancy.

All these components must be presented in the same unit of measurement (hours or days), preferably in hours, and must be calculated for those vessels that have operated in the analyzed group of berths. In order to analyze the occupancy rate and use of the berth, the actual working time of the berth, the non-operating hours due to the port (including those owed to the shippers and / or carriers), the non-operating hours due to port-independent causes (such as bad weather and interruptions due to vessels) resulting in a difference between the total available time and the sum of the aforementioned times as long as the berth was free. In case of these times are recorded on groups of berths, the time thus determined will be averaged.

4. Port facility usage parameters

Port facility usage parameters are a real measure on how the resources and facilities of a berth are used. Although the literature in this field offers extensive information on the use of equipment, storage facilities and human resources involved in ship operation, most of these parameters are of a general nature and do not relate directly to services provided to ships [5, 10, 18]. The research carried out have led to the conclusion that the main parameter in this group is the berth occupancy rate which indicates the actual level of demand for port services during the analyzed period. Additionally, can be used several secondary parameters related to the way in which berth occupancy times are distributed.

From the analysis of the parameters proposed in Table 1, it can be concluded that a high degree of berth occupancy usually indicates port congestion that increases the waiting time of vessels for operation and which often leads to a decrease in the quality of port services. Similarly, high degree of berth occupancy indicates an inefficient use of available port infrastructure resources, which leads to an increase in the cost of port services.

Port activity analysis reveals that the value berth occupancy for each group of berths depends on: the way vessels arrive in port and the possibilities of planning their arrival; the number of berths at which simultaneous operation of the vessels can be performed; the efficiency and flexibility berths assignment system and planning system for vessels operations, the average berthing time of the vessels.

Table 1. Port facility usage parameters

Parameter	Formula	Meaning
Total berth occupancy rate (%)	$g_{tod} = \frac{\sum T_{st_d}}{\sum T_{t_{disp}}} \cdot 100$	the percentage ratio between the total stationary time of all vessels (or groups of inland waterway vessels equivalent to a vessel) in the group of berths considered ($\sum T_{st_d}$, hours) and the total available time of the berths (hours) of that period ($\sum T_{t_{disp}}$, hours).
Actual berth occupancy rate (%)	$g_{od_{ef}} = \frac{\sum T_{serv}}{\sum T_{t_{disp}}} \cdot 100$	the percentage ratio between the actual working time of all vessels operated in the group of berths considered ($\sum T_{serv}$, hours) and the total available time of the berth (hours) during that period ($\sum T_{t_{disp}}$, hours).
Nonuse of the berth due to the port (%)	$g_{nop} = \frac{\sum T_{dp}}{\sum T_{t_{disp}}} \cdot 100$	the percentage ratio between the non-working time due to the port for all vessels operating in the group of berths analyzed ($\sum T_{dp}$, hours) and the total available time of the berths (hours) of that period ($\sum T_{t_{disp}}$, hours).
Nonuse of the berth due to port-independent causes (%)	$g_{nip} = \frac{\sum T_{ip}}{\sum T_{t_{disp}}} \cdot 100$	the percentage ratio between non-working time from port-independent causes, in all vessels, at the berths group considered ($\sum T_{ip}$, hours) and the total available time of the berths (hours) of the period ($\sum T_{t_{disp}}$, hours).

If port costs are taken into account, the effect of a long waiting time on the total vessel's time spent in port, in cases of port congestion and the fact that reducing service time results in a much more substantial reduction in total stationary time vessels in port it appears that there must be a spare capacity to absorb the additional traffic resulting from the spot vessels arrivals.

Therefore, it appears that the tendency to consider that a high rate of berth occupancy indicates an increased berth efficiency is generally wrong. Port experience has shown that for a general cargo terminal a convenient occupancy level is between 60-65%, while for specialized terminals, especially for those where arrivals can be planned rigorously, the occupancy rate can increase up to 80%. In port practice, it is considered that the set of parameters proposed in Table 1 should be calculated for similar berths (which in most cases forms an operating berth front) or a specialized terminal. In order to correctly determine the total occupancy rate of an operating group of berths, it is very important to eliminate “parasite” vessels (berthed vessels with no ongoing operations or vessels carrying out operations which are not related to the traffic carried out by subject berth).

5. Productivity parameters

The port performance parameters proposed above, although providing to a large extent the necessary data for a port information system, they are not reflecting sufficiently the efficiency of the activity and they are not providing enough elements in order to analyze vessel operating costs at berth. Furthermore, as can be seen from their interpretation, they do not indicate how human resources, equipments and storage facilities are used in port activity. Therefore, a set of productivity parameters is needed to assess the efficiency of vessel operations.

In the port context, traffic growth can be achieved either by new investments in port infrastructure and port superstructure, or by hiring manpower, which however entails significant additional production costs. The increase in port traffic can also be achieved by increasing the speed of transfer of cargo from vessels to hinterland or the other way around. Regardless of the type of terminal, it has been found that increased productivity is achieved through a set of organizational measures that allows to reduce vessels operating time and cargo waiting time in port at very low additional costs. The effect of these measures is to achieve the same traffic with fewer resources, thus reducing costs or achieving additional traffic without significant increase in costs, thus significantly increasing the efficiency of port operations.

5.1. Vessel's productivity parameters

The speed with which vessels are operated is the most important parameter of the efficiency of cargo handling at berths. This parameter represents the total quantity of cargo handled by all teams that have worked on vessels that have been operated at a particular group of berths in a specified period.

Table 2. Vessel's productivity parameters

Parameter	Formula	Meaning
Actual average productivity of ship operations (tons/ hours worked)	$P_{mon} = \frac{\sum C_{m_i}}{\sum T_h}$	The ratio between the total quantity of cargo loaded or unloaded from/ to vessels considered (C_{m_i}, tone) and the total hour used for loading/ discharging operations (T_h, hours worked)
Average ship productivity per berth (tons / hours_berth)	$P_{mod} = \frac{\sum C_{m_i}}{\sum T_{st_d}}$	The ratio between the total quantity of cargo loaded/ discharged to/ from vessels considered (C_{m_i}, tons) and the total stationing time at berth (T_{st_d}, hours_berth)
Average productivity of ships in port (tons / hours_berth)	$P_{mod} = \frac{\sum C_{m_i}}{\sum T_{port}}$	The ratio between the total quantity of cargo loaded/ discharged to/ from vessels considered (tons) and the total stationing time in port (hours)
Average number of teams per vessel and shift	N_{med}	Indicates the allocation of resources in the operation of the vessels considered and allows the determination of the average ship productivity or of the one made by a shift.
Average amount of cargo loaded/ discharged on/ off the vessel	C_{mop}	Shows the average amount of cargo operated on the vessel and the way the loading/ discharging operations are carried out

Average team productivity per shift (t/ team hours).	$P_m = \frac{C_{m_{op}}}{N_{m_{ech}} \cdot D_s}$	The average (loaded/ discharged) quantity of one cargo group considered within the set time period ($C_{m_{op}}$, tons) relative to the product of the average number of teams that operated the cargo from that group ($N_{m_{ech}}$) and the duration of a work shift (D_s, ore).

For measuring the operating speed of vessels and to determine the influence of factors involved in determining the vessel's performance, several vessel productivity parameters are used, as shown in Table 2. Port operators' representatives consider that it is often necessary to detail these parameters in order to determine more precisely what are the causes of a productivity lower than expected. For this purpose, several additional information must be available, of which the most important are the operating interruptions for each vessel and main categories of generating factors: caused by the vessel, caused by hydro-meteorological conditions, caused by port operators, caused by reasons external to the operator.

5.2. Labour productivity parameters

The way in which labour is used in port activities is of high importance if it is considered that fact that it is representing 60-70% of operating costs. To show the efficiency of labour utilization, are used a series of specific productivity parameters, as shown in Table 3.

Table 3. Labour productivity parameters

Parameter	Formula	Meaning
The total specific cost of the activity (€/t)	$C_{s_{op}} = \frac{\sum C_i}{\sum C_{m_i}}$	The ratio of the total costs incurred for the activity of a berth in a given period (C_i, *€)* and the total quantity of cargo handled at that berth during the same period (C_{m_i}, tons)
The total specific cost of labor (€/t)	$C_{s_m} = \frac{\sum C_{fmi}}{\sum C_{m_i}}$	The ratio of payments made over a specified period of time (usually one month) to the entire labor force involved in the handling of the cargo at the considered berth (all teams and directly involved staff who worked on the vessel, berth and storage facilities) (C_{fmi}, *€)* and the total quantity of cargo handled at that berth during the same period (C_{m_i}, tons)

Taking into consideration the expenses of the general service staff, the staff involved in the internal transport activity, stacking, lashing etc. as well as other labour-related components will be determined by each operator according to its objectives, but it is essential to maintain the same basis of calculation for the entire period under review.

6. Conclusions

Considering the complexity of the activities carried out in a port, largely generated by the variety of cargoes operated and by the exploitation technologies used, conclusions can only be drawn from the analysis of a sufficiently wide set of performance parameters. The use of these parameters is an essential requirement for a proper analysis of the activities, otherwise there is a risk of incorrect decisions. That is why monitoring an isolated parameter may sometimes prove useful, especially for analysing its evolution.

The overall conclusions on the entire port activity can only be drawn through the analysis of a characteristic and sufficiently wide set of performance parameters that emphasize the multiple faces of a complex activity such as the port logistics system activity and the complex links established between its subsystems.

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