Assessing materials handling and storage capacities in port terminals

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Abstract. Terminals constitute the factual interface between different modes and, as a result, buffer stocks are unavoidable whenever transport flows with different discontinuities meet. This is the reason why assessing materials handling and storage capacities is an important issue in the course of attempting to increase operative planning of logistic processes in terminals. Proposed paper starts with a brief review of the compatibilities between different sorts of materials and corresponding transport modes and after, a literature overview of the studies related to ports terminals and their specialization is made. As a methodology, discrete event simulation stands as a feasible technique for assessing handling and storage capacities at the terminal, taking into consideration the multi-flows interaction and the non-uniform arrivals of vessels and inland vehicles. In this context, a simulation model, that integrates the activities of an inland water terminal and describes the essential interactions between the subsystems which influence the terminal capacity, is developed. Different scenarios are simulated for diverse sorts of materials, leading to bottlenecks identification, performance indicators such as average storage occupancy rate, average dwell or transit times estimations, and their evolution is analysed in order to improve the transfer operations in the logistic process.

1. Introduction

Different categories of goods have different requirements regarding transport, handling and storage, according to its belonging to a specific industry and economic sector. Characteristics presented in literature [1] like: volume, weight, surface, packaging, homogeneity, value and special care are just some of the factors influencing logistic channel uniqueness and lead to specific load units, transport, traffic, infrastructure and transfer costs. In this context, the focus lies on the affinity between commodity and transport mode, meaning that some commodities are more appropriate than others to be transported by means of a certain mode. Some methodologies regarding estimations of the affinity are presented in literature [2] and incorporate factors regarding production (concentration of value, product diversity, requirement concerning purchasing, punctuality, reliability) and distribution (quantity, equipment requirements, logistics structure, number of destinations, speed) [3] allowing an assessment for different categories of materials to corresponding transport modes as in Table 1.

Simplified affinity matrix presented retains only some categories of materials and commodities that involve inland or maritime navigation, extended matrix is in extenso argued in [2].
Table 1. Simplified affinity matrix for different categories of materials to corresponding transport modes (Source [2]).

| Materials/commodities categories | Road | Rail | Inland navigation | Maritime navigation | Intermodal transport |
|----------------------------------|------|------|-------------------|--------------------|----------------------|
| Mining materials                 |      |      |                   |                    |                      |
| Tobacco products                 |      |      |                   |                    |                      |
| Textile products                 |      |      |                   |                    |                      |
| Timber products                  |      |      |                   |                    |                      |
| Petroleum products               |      |      |                   |                    |                      |
| Chemical products                |      |      |                   |                    |                      |
| Metal products                   |      |      |                   |                    |                      |
| Mechanical engineering commodities |    |      |                   |                    |                      |
| Automotive commodities           |      |      |                   |                    |                      |

Legend:
- High affinity
- No affinity
- Poor affinity

2. Handling and storage capacities in cargo terminals

2.1 Port terminals specialization
Random arrival of different types of vessels, shipping specific categories of cargo, makes dwell times quantification a very difficult task, especially for peak hours. Specialized terminals built for all sorts of materials are not affordable for all ports. Literature shows [4], [5] that main answers whether or not to specialize are of different nature: financial, the investments necessary are of great value and can only be justified by a corresponding cargo flow; economic, training of management and labour that can insure the handling speed required by such terminals; space related, land availability for the development of special terminals.

Wide-ranging types of cargo terminals that can be distinguished are: conventional general cargo terminal; container terminal; liquid bulk terminals; dry bulk terminals. In order to be able to assess handling and storage capacities in ports terminals, it is necessary to have some information about: stowage factor for main categories of materials/commodity and about their handling characteristics in terms of method of handling, class of storage, special storage requirement, handling capacities. Some of these characteristics are presented in Table 2.
Table 2. Materials and commodity characteristics influencing port handling and storage capacities (Data source [4]).

| Type of terminal | Main categories of materials/ Commodities | Stowage factor (cubic meters/ton) | Handling characteristics |
|------------------|------------------------------------------|----------------------------------|--------------------------|
|                  |                                          | Bulk/ Bags/Other                 | Method of handling       | Class of storage | Special requirements |
| **Liquid bulk terminals** | Crude oil                               | 1.2                              | Pipeline, hoses          | Tank           | None                   |
|                    | Oil products                             | 1.2                              | Pipeline, hoses          | Tank           | None                   |
|                    | Liquid gas                               |                                  | Pipeline, hoses          | Tank           | None                   |
|                    | Chemical products                        | Barrels, tanks                   | Pipeline, hoses          | Tank           | None                   |
|                    |                                          | 1.5-1.8                          |                          |                |                        |
| **Dry bulk terminals** | Iron ore                                | 0.4                              | Unloader/ belt conveyor  | open           | Dust filters for certain grades |
|                     | Coal                                     | 1.4                              | Unloader/ belt conveyor  | open           | Fire precautions       |
|                     | grains                                   | 1.3 bulk 1.5 bags                | Conveyor                | Covered/ enclosed | Protection from vermin and weevils |
|                     | Phosphoric                               | 1.0                              | Unloader/ conveyor       | Open or closed | Dust filter           |
|                     | Alumina/Bauxite                          | 0.6/0.8                          | Unloader/ conveyor       | Covered        | Cleaning of conveyors |
| **General cargo terminal** | Break bulk                             | 0.4-1.4                          | Tractor, trailers/ Forklifts/ light mobile cranes for open storage | Open/ closed | None                   |
|                    | Palletized, pallets A, B, C, D           | ISO 1A, 1B, 1C, 1D/ non ISO      | Tractor, trailers/ Forklifts/ light mobile cranes for open storage | Covered/ enclosed | None                   |
|                    | pre - slug cargo Containers              | Portainer/terminal tractors with cassis/ gantry cranes/ straddle carriers | Portainer/terminal tractors with cassis/ gantry cranes/ straddle carriers | open           | None                   |
| **Container terminal** | ISO 1A, 1B, 1C, 1D                      | containers                        | Portainer/terminal tractors with cassis/ gantry cranes/ straddle carriers | open           | None                   |
|                    | non ISO                                  | containers                        | Portainer/terminal tractors with cassis/ gantry cranes/ straddle carriers | open           | None                   |
|                    | Bell containers                          | containers                        | Portainer/terminal tractors with cassis/ gantry cranes/ straddle carriers | open           | None                   |
|                    | Tank containers, platforms               | containers                        | Portainer/terminal tractors with cassis/ gantry cranes/ straddle carriers | open           | None                   |
2.2 Essential interactions between the subsystems of general cargo terminal

In order to analyse the port system performance [6], [7] from transfer operation point of view, basic interactions can be incorporated in three subsystems (a fourth port subsystem, navigation command and control one, can be emphasized, but it does not concern transit activities), as follows: berth transfer and handling subsystem, storage subsystems and connected inland transport subsystem.

Conventional general cargo terminal is one of the oldest and, traditionally, is designed for handling of break-bulk and, in time, as it evolved, of load units, unitized general cargo. Concrete experience imposed a general cargo flow scheme as the one presented in Figure 1

![Figure 1](image.png)

**Figure 1.** General cargo flow schedule in a conventional terminal.

General cargo terminal transport connection commonly consists in railway link, road link and inland water terminal provision. For contemporary terminals, direct delivery transshipment rate increased substantially as packed dry bulk cargo gave place to palletized, pre-slung cargo and containers. Anyway, recorded trend is to move the railway connection to a marginal location of the terminal. Road transport is the one that took over a big part of port traffic and problems regarding safe circulation inside ports limits and provision of big size parking place arise.

3. Integration of terminal handling and storage capacities aimed to enhance ports transfer operations

3.1 Methodology

A singular analysis of each port subsystem is required but not sufficient for the complexity of transfer operations [8], [9] because each subsystem interrelates to the other ones as part of a large living entity. Terminals' facilities activity planning and optimisation can be released by means of empirical, analytical or computer simulation techniques [10]. For the reason that analytical solutions have limited capabilities, most of the time, simulation methods are required whenever complex situations of handling and storage facilities evaluation are necessary [11], [12]. When distinct arrival distribution for ship at berths is taken into consideration the probability of refuse is difficult to be evaluated [13].

In order to improve the transfer operations in port terminals, a simulation model, that integrates the activities in terminal and describes the essential interactions between the subsystems that influence the terminal capacity, is developed. Numerical simulation for a port general cargo terminal is carried out by means of a running programme developed in ARENA 5.0. Simulation flow chart is presented in Figure 2.
Characteristics of functional blocks used for simulation are:

*Ships calling type* used to generate homogenous cargo ships arrival distribution that further will be loaded and unloaded in ports storage areas, differentiated for common or special requirements purposes. Attributes of this particular functional block are:

- Arrival time distribution type and corresponding parameters (e.g. average number of arrivals per time unit, mean square deviation etc.)
- Number of ships corresponding to each arrival.

*Cargo characteristics* used for assessment of materials and commodity characteristics in every ship. Attributes of this particular functional block are:

- Type of arrived cargo in warehouse area
- Cargo quantity (quantity distribution type and corresponding parameters)

*Wait for free storage cargo* used for delaying ship until first berth becomes vacant and there is enough space in specific storage area.

*Update storage cargo* used for keeping up to date cargo quantity available in storage areas.

*Berth occupancy* used for assessment of berth transfer occupancy rate for cargo in warehouse areas and loading time period establishment according to cargo quantity arrived and medium handling time per unit of load. Attributes of this particular functional block are:

- Occupied resource (berth) and resources number
- Unloading time (time distribution and corresponding parameters)

*Unloading ship* used for augmentation of warehouse area cargo quantity already stored with current unloaded quantity. Attribute of this particular functional block is cargo unloaded quantity.

*Recording volume* used for listing new parameters in specific results file and prominence of refuse probability (lack of special purposes ports storage areas that leads to common storage space occupancy). Attributes of this particular functional block are:

- Type of arrived cargo
- Unloading starting moment
- Storage areas available cargo quantity and warehouse occupancy rate (occupancy for common or special requirements stacking areas, according to cargo quantities already deposited).

*Free berth* used for berth clearing after ships unloading. Attribute of this particular functional block is free resource, berth

*Trucks calling* used to generate trucks upcoming in order to transfer materials and commodities from warehouse areas, all types of selected cargo. Attributes of this particular functional block are:
- Arrival time distribution type and corresponding parameters (e.g. average number of arrivals per time unit, mean square deviation etc.)
- Arrival schedule (position of arrival time unit in day/24 hours)
- Number of trucks corresponding to each arrival.

*Setting required quantities* used for establishing cargo quantities per truck. Attributes of this particular functional block are cargo quantity distribution type and corresponding parameters (e.g. average number of arrivals per time unit, mean square deviation etc.)

*Loading dock occupancy* used for docks vacancy availability for a truck arrived in order to load from storage areas. Attributes of this particular functional block are occupied resource (*loading dock*) and occupied resources number.

*Stock discontinuity* used for special situations registration of stock gaps (cargo quantity that is available in storage is insufficient to satisfy the demand).

*Release goods from storage* used for evaluation of cargo quantities to be released from storage areas (maximum between demand quantity and stored stock available value), truck loading time computation and release storage areas.

*Loading goods* used for loading dock release after cargo loading time period elapses. Attributes of this particular functional block are released resource (*loading dock*) and released resources number.

### 3.2 Simulation scenarios for diverse sorts of materials

For a general cargo terminal, different scenarios are simulated for diverse sorts of materials, type 1, 2 or 3 cargo according to ports storage areas, differentiated for common or special requirements purposes.

For present simulation purpose, there are 2 berths in terminal; with 2 loading docks and storage area, differentiated for common or special requirements purposes has a capacity of:
- 600 type 1 load units
- 800 type 2 load units
- 800 type 3 load units

The structure of developed model experimental conditions for simulation scenarios is synthetized in Table 3.
Table 3. Experimental conditions for developed simulation scenarios.

| Distribution type                  | Distribution parameters | Concrete values |
|-----------------------------------|-------------------------|-----------------|
| **Ships inter arrival**           | Exponential distribution | Average inter arrival time | 1ship/20hours | 1ship/24hours | 1ship/26hours | 1ship/30hours |
|                                   | Normal (or Gaussian) distribution | Mean value | 1ship/20hours | 1ship/20hours | 1ship/20hours | 1ship/20hours |
|                                   |                         | Variance | 3 | 4 | 4.5 | 5 |
| **Trucks arrival in time window 0800 – 2000** | Uniform distribution | Average number of arrivals per time unit | minimum 3trucks/hour | maximum 5trucks/hour |
|                                   | Exponential distribution | Average number of arrivals per time unit | 4 trucks/hour |
| **Load units arrived in ships**   | Normal (or Gaussian) distribution | Mean value | 250 load units/ships for type 1 cargo* | 300 load units/ships for type 2 cargo* | 300 load units/ships for type 3 cargo* |
|                                   |                         | Variance | 40 | 50 | 50 |
| **Load units released by trucks from storage** | Normal (or Gaussian) distribution | Mean value | 5 load units/truck for type 1* | 6 load units/truck for type 2* | 6 load units/truck for type 3* |
|                                   |                         | Variance | 1 | 1 | 1 |
| **Transfer time ship-storage**    | Triangular distribution | Mean value | minimum 0.95*2*Q<sub>transfer</sub>[min] | maximum 1.05*2*Q<sub>transfer</sub>[min] |
| **Transfer time storage-truck**   | Triangular distribution | Mean value | minimum 0.95*2*Q<sub>transfer</sub>[min] | maximum 1.05*2*Q<sub>transfer</sub>[min] |

*Type 1, 2 or 3 cargos according to ports storage areas, differentiated for common or special requirements purposes

4. Results and conclusions

General experimental parameters for developed simulation model are:

- Number of experiments run – 10;
- Activations carried out after each experiment (resetting the system to initial state);
- Transitory regime time – 5 days;
- Total simulation time – 60 days.

Simulation model results are presented in Figure 3.

Simulation results analysis show an increment of ships dwell times at berths, mostly due to lack of storage space or berth occupancy, for those experiments using exponential distribution type of trucks arrival (Figure 3a) compared to experiments using uniform distribution type of trucks arrival, both distribution with same mean value parameter, as in Table 3.
Figure 3. Average ships dwell time at berth (trucks arrival distribution) exponential for mean value 4 trucks/hour; b) uniform for minimum 3 trucks/hour and maximum 5 trucks/hour.

Large cargo quantities available in storage areas, differentiated for common or special requirements purposes, at initial state, reduce the frequency of stock discontinuity. Stock discontinuity has also lower frequencies for those experiments using exponential distribution type of ships arrival and uniform distribution type of trucks arrival as in Figure 4a).
Average inter arrival time intensification, from 30 to 20 hours, leads to lower frequencies of stock discontinuity especially for those experiments using uniform distribution type of trucks arrival as in Figure 4b.

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6. References
[1] Binsbergen A and Visser J 2001 Innovation Steps towards Efficient Goods Distribution Systems for Urban Areas, TRAIL Thesis Series T2001/5
[2] Sontag H, Meimbresse B and Schimdt C 2010-2013 FLAVIA - Freight and Logistics Advancement in Central/ South-East Europe - Validation of trade and transport processes, Implementation and Application
[3] Dinu O, Rosca E and Rusca F 2016 Maritime Technology and Engineering III Proceedings of the 3rd International Conference on Maritime Technology and Engineering p 53-9
[4] UNCTAD 1986 Port Development. A Handbook for Planners in Developing Countries (New York: United Nations) p 227
[5] Ligteringen H and Velsink H 2012 Ports and Terminals (Delft: VSSD Publisher) p 272
[6] Dinu O, Burciu S, Oprea C and Ilie A 2016 IOP Conference Series: Materials Science and Engineering 145
[7] Burciu S, Stefanica C, Rosca E, Dragu V and Rusca F 2015 IOP Conference Series-Materials Science and Engineering 95
[8] Krenczyk D, Olender M 2014 International Journal of Modern Manufacturing Technologies, Vol. VI, No. 2, p 38-43
[9] Dumbravă Ş 2011 International Journal of Modern Manufacturing Technologies Vol. III, No. 1, 39-44
[10] Agerschou H 2004 Planning and design of port and marine terminals (Thomas Telford: London) p 446
[11] Rusca F, Rosca E, Rusca A, Rosca M and Burciu S 2015 IOP Conference Series-Materials Science and Engineering 95
[12] Rosca E, Raicu S, Rosca M and Burciu S 2014 Advanced Materials Research, 837 p 786-91
[13] Ruscă F, Raicu S, Rosca E, Rosca M and Burciu Ş 2015 Risk assessment for dangerous goods in maritime transport Towards Green Marine Technology and Transport (London: Taylor and Francis Group) p 669-74