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Analysis and modeling of container handling equipment activities

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Abstract

Although the technical literature contains numerous efforts to simulate container terminal performance, little attention has been paid to setting up, calibrating and validating models for handling equipment activities. This paper presents results from the estimation of activity duration concerning three different types of handling equipment: mobile harbor cranes, gantry cranes and reach stackers. Two estimation approaches (sample means vs random variables) were investigated with respect to different hypotheses with regard to activity aggregation and container type (undifferentiated, 20', 40', full or empty). A concise but exhaustive state of art is proposed, an in-depth descriptive analysis of experimental data is carried out, several probability distribution functions were tested and more than 60 statistical models are proposed. The results can be easily implemented in any terminal simulation model.

Keywords: Container terminal; Handling equipment; Time duration; Random variable estimation.

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1. Introduction

The overall task of a container terminal is to manage vessel berthing, inbound container unloading, outbound container loading and storage yards as efficiently as possible. Such a goal can be obtained by coordinating the berthing time of vessels, the resources needed for handling the workload, the waiting time of customer trucks and, at the same time, by reducing congestion on the roads, at the storage blocks and docks. Each of these activities significantly influences port efficiency with consequences on the local and global economy of the freight transport system. In order to manage a container terminal, it is necessary to develop decision support systems able to analyze the system situation, identify system inadequacies or critical points and/or to verify one or more alternative design scenarios.

Although the field of container terminal simulation has been widely tackled in the literature through optimization or simulation approaches, little attention has so far been paid to handling equipment models set-up, calibration and validation. Container

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terminal models have chiefly been on the application and/or comparison of design scenarios, while estimation of handling activity performances appear to be largely overlooked in most of the applications found in the literature. While many contributions present no information on handling equipment models used, the remaining contributions carry out very simple approaches (deterministic) and/or give scant information on the estimation approach pursued, the experimental data used, the parameters estimated and the parameter values.

Given such shortcomings in the existing literature, this paper proposes a concise but exhaustive analysis of the state of the art on handling equipment models and aims to integrate the state of the art itself with respect to the following handling equipments: mobile harbor cranes, gantry cranes and reach stackers. In particular, random variable estimation was compared to sample mean estimation, and different estimation methodologies and different distribution functions were investigated. Moreover, different models were estimated with respect to container type and hypothesizing different level of activity aggregation for each handling equipment. The paper is divided into four sections. The state of the art is reported in section two, calibration of handling equipment models is treated in depth in section three, model validation is described in section four, and the main conclusions are summarised in section five.

2. Handling equipment models: state of the art

As stated in the introduction, to implement a simulation model effectively, estimation of handling performance should be one of the main areas addressed, which does not appear to be the case in most existing applications. Half the papers that give information on the handling equipment models used adopt a stochastic approach and show estimated parameter values. Most of the contributions deal with vessel loading/unloading operations. There is substantial heterogeneity regarding the level of aggregation of activities involved and how such activities are aggregated in a single macro-activity: El Sheikh et al. (1987), Choi and Yun (2000), Kia et al. (2002) and Shabayek and Yeung (2002) analyse the entire time to load (unload) a vessel (vessel cycle time); Koh et al. (1994) and Bugaric and Petrovic (2007) investigate the crane cycle time (time needed to: lock onto the container, hoist and traverse, lower and locate, unlock and return); crane loading time to/from a vessel is analysed by Tugcu (1983), Thiers and Janssens (1998), Yun and Choi (1999), Merkuryeva et al. (2000), KMI (2000), Parola and Sciomachen (2005), Bielli et al. (2006), and Lee and Cho (2007).

As regards vessel cycle time, a stochastic approach is unanimously proposed. In particular, El Sheikh (1987), Kia et al. (2002) and Shabayek and Yeung (2002) suggest using Erlang random variables whereas Choi and Yun (2000) proposes normal random variables for two crane types (quay, yard). As regards crane cycle time, Koh et al. (1994) advise the use of a Weibull random variable; Bugaric and Petrovic (2007), for a bulk cargo terminal, propose normal random variables and report the estimated parameters.

Table 1: Survey of handling models: Gantry crane (GC).

Operation/ activity	*Handling equipment*	*Reference*	*Handling model proposed*	
Crane operation time	Quay GC	Yun and Choi (1999)	Exponential	Mean = 0.50 (min)
		Lee and Cho (2007)		Mean = 1.00 (min)
		Merkuryeva et al. (2000)	Uniform	Min.=2.00 (min.) Max=4.00 (min.)
		Bielli et al. (2006)	Deterministic	Mean = 1.50 (min)
	Yard GC	Yun and Choi (1999)	Exponential	Mean = 1.00 (min)
		Merkuryeva et al. (2000)	Triangular	40' loading : Mean = 6.00 (min) 40' unloading : Mean = 4.00 (min) S.d. = 0.41 (min)
		Lee and Cho (2007)		Mean = 1.55 (min) s.d. = 0.08 (min)
		Bielli et al. (2006)	Deterministic	Mean = 1.50 (min)
	n.s.*	Parola and Schiomachen (2005)	Normal	Not reported
		Tugcu (1983)	Deterministic	Not reported
		Thiers and Janssens (1998)	Deterministic	Not reported
		KMI (2000)	Deterministic	Not reported
Crane cycle time	n.s.*	Koh et al. (1994)	Weibull	Not reported
	Bulk cargo	Bugaric and Petrovic (2007)	Normal	Mean = 5.00 (min) s.d. = 0.26 (min)
Vessel cycle time	Quay GC	Choi and Yun (2000)	Normal	Mean = 112.80 (min) s.d. = 5.60 (min)
	Yard GC	Choi and Yun (2000)	Normal	Mean = 87.00 (min) s.d. = 13.89 (min)
	Entire loading operation	El Sheikh (1987)	Erlang	Mean = 4.20 (day) K = 4.33
	Entire unloading operation	El Sheikh (1987)	Erlang	Mean = 7.57 (day) K = 10.77
	n.s.*	Kia et al. (2002)	Erlang	Mean = 37.85 (hour) K = 4.00
		Shabayek and Yeung (2002)	Erlang	Mean ∈ [9.6, 16.3] (hour) K = 117
Crane speed	Quay Gantry crane	Yun, Choi (1999)	Deterministic	45 (metres/min.)
		Legato et al. (2008)	Deterministic	45 (metres/min.)
		KMI (2000)	Deterministic	45 (metres/min.)
	Hoist with Full load	KMI (2000)	Deterministic	55 (metres/min.)
	Hoist without Load			130 (metres/min.)
	Ship trolley			180 (metres/min.)
	Store trolley			75 (metres/min.
	Yard Gantry crane	Choi and Yun (2000)	Deterministic	134 (metres/min.)
	n.s.*	Tugcu (1983)	Deterministic	Not reported
		Koh et al. (1994)	Deterministic	Not reported
		Thiers and Janssens (1998)	Deterministic	Not reported

Note: * n.s. = handling equipment type or the type of activity are not specified.

With regard to crane loading/unloading time, Tugcu (1983), Thiers and Janssens (1998), KMI (2000) and Bielli et al. (2006) follow a deterministic approach, contrasting with the stochastic approach adopted by Yun and Choi (1999), Merkuryeva et al. (2000), Lee and Cho (2007), and Parola and Sciomachen (2005). Yun and Choi (1999) propose the exponential distribution function both for quay cranes and yard cranes; Merkuryeva et al. (2000) propose the uniform distribution function for quay cranes and a triangular distribution function for yard gantry cranes; Lee and Cho (2007) suggest the exponential distribution function for quay crane and a triangular distribution function for yard gantry crane operation time. Parola and Sciomachen (2005) estimated a normal random variable but do not report parameter values. With respect to crane speed, all propose deterministic and aggregate models while only Yun and Choi (1999), Choi and Yun (2000), KMI (2000) and Legato et al. (2008) report the estimated mean values.

With respect to other handling equipment, not much can be found in the literature: Sgouridis and Angelides (2002) use deterministic values for a straddle carrier, whereas Merkuryeva et al. (2000) propose a triangular distribution function for the forklift. As regards shuttle performances (speed, travel time, waiting time …), the few models existing are hard to transfer to different case studies (due to the influence of path length, path winding, vehicle congestion inside the terminal and so on).

A synopsis of the above analysis is presented in tables 1, 2 and 3. For each type of handling equipment and for each activity simulated, probability distribution and corresponding parameters are reported.

Table 2: Survey of handling models: Straddle carrier (SC).

Operation/activity	*Handling equipment*	*Reference*	*Handling model proposed*	
Speed	Straddle carrier	Sgouridis and Angelides (2002)	Deterministic	Inside yard: 110(met./min.) Outside yard: 250 (met./min.)
Shuttle loading/ Unloading time			Deterministic	0.60 (min.)
Spreader movement Turning			Deterministic	0.30 (min.)
			Deterministic	0.02 (min.)
Container spotting			Deterministic	1.00 (min.)

Table 3: Survey of handling models: Forklift (FL).

Operation /activity	*Handling equipment*	*Reference*	*Handling model proposed*	
Loading/ Unloading time	Forklift	Merkuryeva et al. (2000)	Triangular	20’ loading Mean = 4.00 (min.) St. Dev. = 0.41 (min.)
				20’ unloading Mean = 3.00 (min.) St. Dev. = 0.41 (min.)

3. Handling equipment models calibration

3.1 Methodology and case study

In this section, handling equipment times are estimated. Sample means and estimations of random variables are explored for each elementary handling activity of each type of handling equipment. Two different estimation methodologies and different distribution functions were tested on experimental data taken from a survey carried out between January 2003 and July 2005 inside the Salerno Container Terminal (SCT).

Whilst being one of the major private container terminals in the south of Italy, SCT is also a small and very efficient terminal, reaching 0.4 million TEUs in 2007, or 40,000 TEUs/ha. The terminal operates five ship-to-shore cranes, all equipped with twin-lift spreaders (3 post panamax with a 17-row out-reach and 2 panamax with max 15 rows out-reach), in an area of approximately 120,000 m2, used for the storage of full and empty containers. Container berths making up a total quay length of 890 metres are available, supplemented by 1,120 meters of quay length for additional requirements. RTGs, reachstackers, top-loaders and a substantial fleet of dockside handling equipment including multi-trailer-trains for transporting containers from operational to stacking areas, ensure a high level of productivity and fast despatch.

From January 2003 to July 2005 the whole container terminal was monitored (more than 1,000 vessels were monitored). The data acquired were used for analysis of the vessel, gate and yard macro-areas, and particularly for estimation of the berth-side/land-side demand (per container type and time period) at the container terminal.

Jointly with these data, an integrative survey was carried out during the first six months of 2005. In particular, all the berth macro-area activities involving more than 3,000 containers were monitored (equal to 20% of the containers loaded/unloaded per month and 1% of the containers loaded/unloaded per year), each of which was traced from its origin to its final destination. Each trip was subdivided into homogeneous activities (see table 4) and for each activity the time duration was measured and the resulting data were classified according to the following classes: 20’ (full and/or empty), 40’ (full and/or empty), 2 x 20’ (full). Finally, four different handling models were estimated:

- *sample mean* as estimation of activity time duration*;*
    - Sample Mean Undifferentiated (SMU) model, where no differentiation was made among containers type;
    - Sample Mean Container Type (SMCT), where the following container types were taken into account (20’ full and/or empty; 40’ full and/or empty; 2 x 20’ full);
- *random variable* as representative of activity time duration;
    - Random Variable Undifferentiated (RVU) model (see above);
    - Random Variable Container Type (RVCT) models (see above).

Table 4: Activities analyzed for each handling equipment.

Mobile harbour crane (MHC)	*Gantry crane (GC)*	*Reach stacker (RS)*
Loading from dock to vessel	Unloading to shuttle/truck	Unloading from shuttle/truck
Loading from shuttle to vessel	Loading from shuttle/truck	Loading to shuttle/truck
Unloading from vessel to dock	Unloading to stack	Stacking to tier
Unloading from vessel to shuttle	Loading from stack	
	Trolley movement with container	
	Free trolley movement	
	Crane movement	

The analyses are divided into preliminary descriptive analysis of experimental data and statistical analysis. In the descriptive analysis, the mean values and corresponding standard deviations are estimated. Such values are useful to develop/implement a decision support models based on sample mean variables, and allow the need for a stochastic approach to be appreciated.

By contrast, statistical analysis aims to estimate the theoretical continuous cumulative distribution function $F_X(\underline{x};\ \mu, \sigma)$ that best fits the sample distribution function $F^{sample}(\underline{x}; n)$. Given a sample $\underline{x} = (x_1, \ldots, x_n)$, with mean $\overline{x}$ and variance s^2, *Kolmogorov-Smirnov* statistic was used to evaluate the quality of the estimation methodology and the random variable tested:

$$D_n = sup \mid F^{sample}(\underline{x}; n) - F_X(\underline{x}; \mu, \sigma) \mid = D_{n,X(\mu,\sigma)}(\underline{x})$$

For large values of n, Smirnov (1948) gives the limiting distribution of $D_n \cdot n^{1/2}$; it is thus possible to compute the critical values $d_{n,\alpha}$ (the thresholds) for large samples (n>35):

$$d_{n,\alpha} = 1.3581 / n^{1/2} \text{ for } \alpha = 0.05$$
$$d_{n,\alpha} = 1.6276 / n^{1/2} \text{ for } \alpha = 0.01$$

For smaller sample sizes the critical values are estimated in Miller (1956).

The *Kolmogorov-Smirnov* statistic with respect to two sample distributions is the statistic used to evaluate whether two sample distributions are the same from a statistical point of view. This statistic was used to evaluate whether sample distributions related to similar activities are equal (for example whether the sample distribution related to the 20’ full container loading time is same as the sample distribution for the 20’ empty container loading time).

Two estimation methods were compared: moment estimation and maximum likelihood (M-L) estimation. Several variables (exponential, log normal …) were tested for each activity introduced in table 4 and for different container types.

The estimation results show differences in terms of parameter value variables between 0.5% and 12%. From a statistical point of view, M-L estimations show the best results. Furthermore, sometimes the moment D_n values are greater than the corresponding thresholds $d_{n,\alpha}$. These results suggest we should prefer M-L model estimation.

Comparison among different models (random variables) shows that only Normal, Gamma and Weibull random variables were statistically significant. The three random variables produce D_n values below the thresholds; however, D_n values related to the Gamma random variable may often be below the others. It can be concluded that, while the three random variables could all be used to represent the time duration of the main container terminal handling activities, the Gamma random variable produces the best results. In the following, the main results are shown for both analyses.

3.2 Calibration results

3.2.1 Mobile harbour cranes (MHCs)

The MHCs operating in the Salerno Container Terminal are three Gottwald HMK 260 mounted on rubber tyres; these are particularly popular in ports and terminals frequented by feeders and other vessels with widths of up to 25 metres. This equipment is also suitable for twin-lift (2 x 20’ full) cargo containers. MHC activities are mainly devoted to loading/unloading containers to/from berthed vessels.

The analyses carried out concern loading activities from shuttle to vessel or from dock to vessel, and unloading activities from vessel to dock. The following container types were considered: undifferentiated containers, 20’, 40’ and 2x20’. Since most Salerno Container Terminal loading/unloading activities concern full containers, the analysis mainly focused on these. Some results on empty containers are proposed only for activities that systematically involve such containers.

As regards undifferentiated containers, the results reported in table 5 show an average MHC unloading time of 0.871 minutes and a corresponding standard deviation of 0.263 minutes, 30% less than the average. For loading activities the standard deviation (0.657 min) is 46% below the average (1.426 min). Such results show that loading activities such as container alignment in the hold are more subject to unexpected events (e.g. problems with the spreader and poor visibility during stowing). Distinguishing *loading from dock* to vessel and *from shuttle* to vessel, it is worth noting that average loading time from dock is almost equal to the average loading time from shuttle; while standard deviations are quite different (17%) and turn out to be more than 50% less than the average value.

The same analysis carried out for container type (20’, 40’ and 2x20’) shows that MHC performance changes as the container size changes. For *loading from dock*, loading time is 1.316 minutes for 20’ full containers and 1.494 minutes for 40’ full containers (14% greater). Standard deviations differ from zero and are about 60% lower than the corresponding averages, appreciably varying with container type: 0.485 minutes for 20’ full containers and 0.632 minutes for 40’ full containers (30% greater). Such results confirm that container types should be taken into account and the need for a stochastic approach.

As regards *loading time from shuttle,* no significant differences can be observed between 20’ full and 40’ full, standard deviations differ from zero and are about 60% less than the average values. Comparing *loading time from dock* and *from shuttle*, it should be pointed out that *loading from dock* needs more time (≈ +17%) both for 20’ full and 40’ full, and show higher dispersions: +20% for 20’ full containers, +40% for 40’ full containers.

Finally, since MHCs can move two 20’ containers at the same time (2x20’), the loading time for 2x20’ full containers was estimated. Estimates show an average loading time of 2.214 minutes and a standard deviation of 0.926 minutes. Interestingly, the loading time is 8% less than the time required to load two 20’ full containers in succession, and the standard deviation is 60% greater than the standard deviation of loading time of a 20’ full container.

There is essentially one activity that involves empty containers: *loading from shuttle*. It is worth noting that standard deviation is similar to those estimated for 20’ full and 40’ full, while the average loading time is 13% less than 40’ full and only 6% less than 20’ full.

Similar analyses were carried out for vessel unloading activities. In this case we refer only to the unloading time from vessel to dock, since activities from vessel to shuttle are not frequent in the Salerno Container Terminal.

The estimates (see also table 5) show similar average unloading time and standard deviations for both 20’ full containers and 40’ full container, in particular standard deviations differ from zero and, for all types, are 30% less than the corresponding averages. Unloading time of 2x20’ containers is not substantially different (+12%) from the unloading time of a single container; in this case, moving two containers at the same time is much more effective. Finally, unloading times for 20’ empty containers were estimated. While the average unloading time is 11% less than the time to unload a 20’ full or a 40’ full, the standard deviation (0.216 minutes) is 2% smaller than the corresponding standard deviations of both 20’ full or a 40’ full.

Table 5: Mobile harbour crane (MHC) empirical results.

Activity Time (minutes)	*Undifferentiated*		*20’*				*40’*				*2 x 20’*	
			Empty		*Full*		*Empty*		*Full*		*Full*	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Loading	1.426	0.657	1.102	0.385	1.257	0.444	1.121	0.386	1.332	0.476	2.214	0.926
Unloading	0.871	0.263	0.768	0.216	0.856	0.221	n.p.	n.p.	0.867	0.230	0.971	0.366
Loading from dock	1.398	0.562	n.p.	n.p.	1.316	0.485	n.p.	n.p.	1.494	0.632	n.p.	n.p.
Loading from shuttle	1.435	0.678	1.102	0.385	1.193	0.387	1.121	0.386	1.272	0.389	2.214	0.926
Unloading to dock	0.871	0.263	0.768	0.216	0.856	0.221	n.p.	n.p.	0.867	0.230	0.971	0.366

Notes: n.p. = not present / n.a. = not available.

Statistical analysis for undifferentiated containers shows that the Gamma distribution function is always statistically significant, while Normal and Weibull distribution functions do not always verify the K-S test. The same random variable seems to be the best approximation for loading and unloading activities that involve 20’ and 40’ (full or empty) containers. In table 6 means and standard deviations are reported for each activity (related to M-L estimation and Gamma distribution). Values are consistent with those introduced in the descriptive analysis and may be interpreted in the manner discussed above.

Table 6: Mobile harbour crane (MHC) statistical results: parameters of the Gamma distribution function (M-L estimation).

Activity Time (minutes)	Undifferentiated		20'				40'				2 x 20'	
			Empty		Full		Empty		Full		Full	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
Loading	1.366	0.514	1.084	0.387	1.238	0.405	1.101	0.340	1.288	0.402	2.083	0.690
Unloading	0.862	0.214	0.664	0.139	0.825	0.183	N.p.	N.p.	0.835	0.188	0.933	0.326
Loading from dock	1.389	0.441	n.p.	n.p.	1.252	0.407	n.p.	n.p.	1.372	0.485	n.p.	n.p.
Loading from shuttle	1.350	0.549	1.084	0.387	1.227	0.405	1.101	0.340	1.244	0.375	2.083	0.690
Unloading to dock	0.862	0.214	0.664	0.139	0.825	0.183	n.p.	n.p.	0.835	0.188	0.933	0.326

Notes: n.p. = not present / n.a. = not available.

As stated before, *Kolmogorov-Smirnov* validation test was used. With respect to the M-L estimation, in table 7 the D_n values and thresholds $d_{n,\alpha}$ (with $\alpha = 0.05$) are reported. As we can see, the D_n values are always lower than the correspondent $d_{n,\alpha}$ thresholds.

Table 7: Mobile harbour crane (MHC) statistical results: validation test outputs (M-L estimation).

Activity Time (minutes)	Undifferentiated		20'				40'				2 x 20'	
			Empty		Full		Empty		Full		Full	
	Dn	dn,α	Dn	dn,α	Dn	dn,α	Dn	dn,α	Dn	dn,α	Dn	dn,α
Loading	0.049	0.050	0.050	0.115	0.049	0.112	0.048	0.109	0.050	0.112	0.053	0.118
Unloading	0.048	0.050	0.056	0.101	0.062	0.102	n.p.	n.p.	0.037	0.100	0.064	0.101
Loading from dock	0.069	0.071	n.p.	n.p.	0.096	0.134	n.p.	n.p.	0.067	0.150	n.p.	n.p.
Loading from shuttle	0.068	0.071	0.062	0.136	0.059	0.136	0.060	0.136	0.032	0.087	0.059	0.133
Unloading to dock	0.048	0.050	0.090	0.160	0.045	0.074	n.p.	n.p.	0.053	0.094	0.098	0.155

Notes: n.p. = not present / n.a. = not available.

3.2.2 Gantry cranes (GCs)

The GCs operating in the Salerno Container Terminal are four rubber-tyred gantry cranes used both for movement/storage of containers and for loading of shuttles/trucks. This crane type usually consists of three separate movements for container transportation. The first movement is performed by the hoist, which raises and lowers the container. The second is the trolley gear, which allows the hoist to be positioned directly above the container for placement. The third is the gantry, which allows the entire crane to be moved along the working area.

The analyses carried out concern loading and unloading to the shuttle/truck, and loading and unloading to the stack (sometimes called pile). Each activity was analyzed distinguishing undifferentiated containers from 20’ and 40’ containers. Moreover, loading time from stack was analyzed, further distinguishing the tier. The analysis focused on full containers, since these activities are the most frequent in the Salerno Container Terminal.

As regards loading time of undifferentiated containers (see table 8), the differences between loading time from shuttle and from stack (all tiers) are smaller. Average loading time from shuttle (0.888 min) is 13% greater than the loading time from stack, while loading time from shuttle standard deviation (0.352 min) is 10% smaller than loading time from stack standard deviation. In terms of loading time from stack for each tier, it can be pointed out that the mean decreases as the tier number increases. In particular, a significant difference (>30%) can be observed for the standard deviations between the 1st and 2nd tiers, whereas from the 2nd to 5th tiers, the standard deviation increase can be considered negligible.

Only for loading time from stack are data available for container type. As for undifferentiated containers, average loading time from stack decreases as the tier number increases. This trend holds both for 20’ full and 40’ full containers. Comparing the averages for each tier number, small differences (about 1% or 2%) can be observed among container type. More appreciable differences exist among the different tiers. With respect to tier 1, loading time increases more than 30% for tier 2, more than 34% for tier 3 and more than 40% for tiers 4 and 5; differences among tiers from 2 to 5 are negligible. As regards the standard deviations, considerable differences can be observed between container type and between the different tiers. With respect to 40’ full containers, 20’ full container standard deviation is 46% less for tier 1, 81% less for tier 2, and more than 100% less for tiers 3, 4 and 5. With respect to undifferentiated containers, smaller standard deviations can be observed for 20’ full containers (-20% for tier 1, -30% for tier 2, -40% for tier 3), whereas greater standard deviations can be observed for 40’ full containers (+20% for tier 1, +26% for tier 2, +24% for tier 3).

As regards unloading of undifferentiated containers, the results (see table 8) show an average unloading time to shuttle (equal to 1.331 min) which is 40% greater than the unloading time to stack (average on all tiers). For both activities the standard deviations differ from zero and are about 30% smaller than the corresponding average values.

In particular, the unloading time to shuttle shows a 30% greater standard deviation (0.434 min) than the standard deviation of unloading time to stack (0.309 min). These results confirm that unloading to a shuttle/truck or stack should be analyzed through a stochastic approach; furthermore, unloading to a shuttle/truck requires more time than loading due to the time required to align the container to the shuttle, and shows higher dispersion due to the greater number of unexpected events that may occur in such operations (e.g. problems with container blocks on the shuttle or poor visibility during unloading). Carrying out the same analyses for 20’ and 40’ full containers, the estimation results show small differences (≈5%) for average values, but more appreciable for standard deviations (13%).

As regards unloading time to stack, no differences were observed among container types and the analyses were carried out distinguishing the unloading activities with respect to the tier number. The results show that average unloading time, as expected, decreases as the tier number increases, and there are no significant differences from tier 3 to tier 5, while the differences between tiers 1 and 2 (46%) and tiers 1 and 3 (58%) are significant. Unlike average values, standard deviations increase between tiers 1 and 2 while they decrease among tiers greater than 2.

Table 8: Gantry crane (GC) empirical results (minutes).

Activity Time (minutes)	*Undifferentiated*		*20'*		*40'*	
			Full		*Full*	
	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*
Loading (from shuttle)	0.888	0.352	n.a.	n.a.	n.a.	n.a.
Unloading (to shuttle)	1.331	0.434	1.303	0.460	1.367	0.402
Loading (from stack)	0.769	0.380	0.758	0.283	0.774	0.422
Unloading (to stack)	0.760	0.309	N.a.	N.a.	N.a.	N.a.
Loading (from stack) - tier 1	1.025	0.431	1.019	0.348	1.031	0.509
Loading (from stack) - tier 2	0.713	0.270	0.706	0.188	0.721	0.340
Loading (from stack) - tier 3	0.672	0.290	0.658	0.169	0.683	0.361
Loading (from stack) - tier 4	0.625	0.374	0.618	0.236	0.636	0.401
Loading (from stack) - tier 5	0.614	0.376	0.605	0.261	0.623	0.415
Unloading (to stack) - tier 1	1.101	0.236	No significant differences with respect to undifferentiated containers			
Unloading (to stack) - tier 2	0.753	0.339				
Unloading (to stack) - tier 3	0.699	0.312				
Unloading (to stack) - tier 4	0.647	0.309				
Unloading (to stack) - tier 5	0.640	0.307				

Notes: n.p. = not present / n.a. = not available.

Finally, averages and standard deviations were estimated for trolley speed and crane speed. As reported in table 9, the average full trolley speed (trolley with a container) is equal to 13 metres/minute (with a standard deviation of more than 6 m/minute) and it is 74% lower than the free trolley speed (50 m/minute, with a standard deviation of more than 30 m/minute). With respect to crane speed, the estimation results show an average speed of about 13 m/minute (with a standard deviation of about 6 m/minute). Distinguishing by container type, the difference between average trolley speed averages is negligible (≈ 6%), the differences between standard deviations (≈ 65%) point to the need for a stochastic approach.

For all the described activities and for each container type, in-depth analysis was developed to find the statistical distribution which best fitted the data. Three distribution functions were statistically significant: Gamma, Normal and Weibull. As regards undifferentiated containers, the Gamma distribution function proved the best solution for all analysed activities. Similar results were achieved on analyzing activities for each container type and each tier number. In tables 10 and 11 means and standard deviations are reported for each activity (related to M-L estimation and Gamma distribution). Values are consistent with those introduced in the descriptive analysis and may be interpreted in the manner discussed above.

Table 9: Gantry crane (GC) empirical results (m/min).

Activity *Speed (meters/ minutes)*	*Undifferentiated*		*20'*		*40'*	
			Full		*Full*	
	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*
Trolley speed (with container)	12.663	6.416	13.243	4.142	12.508	6.902
Free trolley speed	49.076	30.202	-	-	-	-
Crane speed	12.916	5.515	n.a.	n.a.	n.a.	n.a.

Notes: n.p. = not present / n.a. = not available.

Table 10: Gantry crane (GC) statistical results: parameters of the Gamma distribution function (M-L estimation).

Activity *Time (minutes)*	*Undifferentiated*		*20'*		*40'*	
			Full		*Full*	
	μ	σ	μ	σ	μ	σ
Loading (from stack)	0.752	0.406	0.741	0.311	0.769	0.457
Unloading (to stack)	0.766	0.352	n.a.	n.a.	n.a.	n.a.
Loading (from stack) - tier 1	1.022	0.449	1.011	0.353	1.060	0.561
Loading (from stack) - tier 2	0.687	0.250	0.658	0.222	0.712	0.256
Loading (from stack) - tier 3	0.668	0.323	0.659	0.246	0.673	0.383
Loading (from stack) - tier 4	0.592	0.325	0.583	0.261	0.606	0.390
Loading (from stack) - tier 5	0.571	0.355	0.560	0.280	0.584	0.399
Unloading (to stack) - tier 1	1.097	0.231	No significant differences With respect to Undifferentiated containers			
Unloading (to stack) - tier 2	0.703	0.308				
Unloading (to stack) - tier 3	0.671	0.256				
Unloading (to stack) - tier 4	0.638	0.245				
Unloading (to stack) - tier 5	0.613	0.240				

Notes: n.p. = not present / n.a. = not available.

Table 11: Gantry crane (GC) statistical results: parameters of the Gamma distribution function (M-L estimation).

Activity *Speed (meters/ minutes)*	*Undifferentiated*		*20'*		*40'*	
			Full		*Full*	
	μ	σ	μ	σ	μ	σ
Trolley speed (with container)	11.653	4.597	12.740	4.275	11.203	4.530
Free trolley speed	46.609	29.892	-	-	-	-
Crane speed	11.498	4.586	n.a.	n.a.	n.a.	n.a.

Notes: n.p. = not present / n.a. = not available.

In table 12 and 13, D_n values and $d_{n,\alpha}$ thresholds (with $\alpha = 0.05$) are reported. As we can see, the D_n values are always lower than the correspondent $d_{n,\alpha}$ thresholds.

Table 12: Gantry crane (GC) statistical results: validation test outputs (M-L estimation).

Activity	*Undifferentiated*		*20’*		*40’*	
			Full		*Full*	
	Dn	*dn,α*	*Dn*	*dn,α*	*Dn*	*dn,α*
Loading (from stack)	0.065	0.100	0.092	0.142	0.088	0.142
Unloading (to stack)	0.045	0.130	0.064	0.184	0.065	0.184
Loading (from stack) - tier 1	0.062	0.196	0.062	0.269	0.101	0.269
Loading (from stack) - tier 2	0.084	0.202	0.101	0.275	0.143	0.294
Loading (from stack) - tier 3	0.055	0.185	0.077	0.269	0.106	0.242
Loading (from stack) - tier 4	0.101	0.250	0.147	0.363	0.143	0.363
Loading (from stack) - tier 5	0.097	0.264	0.141	0.384	0.151	0.384
Unloading (to stack) - tier 1	0.094	0.238	No significant differences With respect to Undifferentiated containers			
Unloading (to stack) - tier 2	0.075	0.238				
Unloading (to stack) - tier 3	0.063	0.238				
Unloading (to stack) - tier 4	0.095	0.327				
Unloading (to stack) - tier 5	0.095	0.327				

Note: n.p. = not present.

Table 13: Gantry crane (GC) statistical results: validation test outputs (M-L estimation).

Activity	*Undifferentiated*		*20’*		*40’*	
			Full		*Full*	
	Dn	*dn,α*	*Dn*	*dn,α*	*Dn*	*dn,α*
Trolley speed (with container)	0.069	0.100	0.105	0.217	0.086	0.112
Free trolley speed	0.066	0.144	-	-	-	-
Crane speed	0.094	0.248	n.a.	n.a.	n.a.	n.a.

Notes: n.p. = not present / n.a. = not available.

3.2.3 Reach stackers (RSs)

Eleven RSs operate in the Salerno Container Terminal, equipped with a twin-lift spreader able to move two full 20’ containers. They are used both to transport containers very quickly over short distances and to pile/stow them in various rows.

The analyses concern: loading to shuttle/truck, unloading from shuttle/truck and stacking. Each activity was analyzed distinguishing undifferentiated containers from 20’ and 40’ containers. Moreover, stacking was analyzed distinguishing the tier number. The analysis focused on full containers since the main activities in Salerno Container Terminal concern full containers.

As regards undifferentiated containers (table 14), reach stacker unloading activities show an average unloading time from shuttle/truck of 0.215 minutes and a standard deviation of 0.114. With respect to stacking time, the estimation results show an average (calculated with respect to tier, up to five, in which a container is stacked) stacking time of 0.288 minutes and a standard deviation of 0.157 minutes. For all the activities, the standard deviation values confirm the need of a stochastic approach.

Interesting results can be observed on distinguishing between container types. With regard to loading, an average time of 0.365 minutes was observed for the 40' full container (with a standard deviation of 0.272 minutes) and 0.344 minutes for the 20' full container (with a standard deviation of 0.205 minutes). It can be concluded that the averages and corresponding standard deviations are similar and independent of container type.

As regards unloading, the average time for a 20' full container is 0.153 minutes (with a standard deviation of 0.055 minutes), whereas it is double for the 40' full container in terms of average (0.236 minutes) and standard deviation (0.119 minutes). For this activity, average values and standard deviations differ considerably (almost 50%) from undifferentiated values and, along with the high number of activities in which RSs are involved, show that different hypotheses on aggregation levels may lead to very different results and that such an issue should be carefully weighed up in the micro-simulation of a terminal container.

For stacking time, the time duration for each tier (up to five) was computed, but it was not possible to distinguish container type. With respect to tier 1, the average estimated stacking time is 0.201 minutes (with a standard deviation of 0.062 minutes), 0.186 minutes for tier 2 (with a standard deviation of 0.077 minutes), 0.238 minutes (with a standard deviation equal to 0.098 minutes) for tier 3, 0.355 minutes (with a standard deviation of 0.148 minutes) for tier 4 and 0.542 minutes (with a standard deviation of 0.164 minutes) for tier 5. Activity duration increases as the tier increases except for tier 2 which shows the lowest time duration since the arm of the RS is positioned at the same height as tier 2. The standard deviations are independent of the tier in which a container is stacked.

Starting from the same data, several random variables were tested. For RS loading and unloading, only Gamma and Weibull variables met the statistical significance tests: the Gamma random variable fits the data better due to better values in the validation test. In table 15, the results are shown and comments may be made similar to those proposed before for empirical analysis.

Table 14: Reach stacker (RS) empirical results.

Activity Time (minutes)	*Undifferentiated*		*20'*		*40'*	
			Full		*Full*	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Loading to shuttle/truck	0.357	0.250	0.344	0.205	0.365	0.272
Unloading from shuttle/truck	0.215	0.114	0.153	0.055	0.236	0.119
Stacking time	0.288	0.157	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 1	0.201	0.062	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 2	0.186	0.077	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 3	0.238	0.098	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 4	0.355	0.148	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 5	0.542	0.164	n.a.	n.a.	n.a.	n.a.

Notes: n.p. = not present / n.a. = not available.

Table 15: Reach stacker (RS) statistical results: parameters of the Gamma distribution function (M-L estimation).

Activity Time (minutes)	*Undifferentiated*		*20'*		*40'*	
			Full		*Full*	
	μ	*σ*	*μ*	*σ*	*μ*	*σ*
Loading to shuttle/truck	0.307	0.170	0.304	0.155	0.311	0.188
Unloading from shuttle/truck	0.186	0.074	0.144	0.056	0.200	0.087
Stacking time	0.260	0.146	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 1	0.185	0.056	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 2	0.167	0.071	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 3	0.212	0.086	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 4	0.334	0.118	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 5	0.542	0.140	n.a.	n.a.	n.a.	n.a.

Notes: n.p. = not present / n.a. = not available.

As regards RS speed, the authors suggest estimating the time duration of these activities directly. In this case, statistical models are not easily transferable since they depend on peculiarities of the container terminal: geometrical characteristics (path winding, …..), traffic congestion, etc..

In table 16 D_n validation test values and $d_{n,\alpha}$ thresholds (with $\alpha = 0.05$) are reported. As we can see, also for the reach stacker models, the D_n values are always lower than the correspondent $d_{n,\alpha}$ thresholds.

Table 16: Reach stacker (RS) statistical results: validation test outputs (M-L estimation).

Activity	*Undifferentiated*		*20'*		*40'*	
			Full		*Full*	
	Dn	*dn,α*	*Dn*	*dn,α*	*Dn*	*dn,α*
Loading to shuttle/truck	0.072	0.085	0.081	0.166	0.104	0.120
Unloading from shuttle/truck	0.090	0.103	0.075	0.215	0.175	0.287
Stacking time	0.095	0.110	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 1	0.084	0.231	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 2	0.149	0.223	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 3	0.117	0.246	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 4	0.104	0.246	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 5	0.232	0.269	n.a.	n.a.	n.a.	n.a.

Notes: n.p. = not present / n.a. = not available.

4. Handling equipment models validation and comparison

The aim of this section is to validate the handling models proposed in section 3 (SMU, SMCT, RVU and RVCT) and to compare the effectiveness of the proposed approaches (sample mean estimation vs random variable estimation; container type differentiation vs no differentiation).

The handling model outputs were compared with the data surveyed in 2003 in the container terminal in order to ascertain the suitability of the model for representing real conditions. Model validation was carried out, estimating goodness of fit for each of the proposed models with respect to:

- single container movement time. This allows measurement of the model's ability to simulate single container movement. Such validation could be insightful in the event of the need to implement a short-term/real-time planning strategy, where simulation of single container movements should be as realistic as possible.
- Handling equipment operation time. This allows measurement of the model's ability to simulate handling equipment operation time. Such validation could be useful to understand which handling equipment is most affected by different modelling hypotheses and could be insightful for implementing short/medium term planning strategies.

As regards single container terminal time, with respect to a set of monitored terminal operations container movement times were estimated and compared with observed times. Absolute percentage error was estimated for each container and a global measure was obtained by summing each percentage error.

As regards handling equipment operation time, for each elementary activity and for the containers involved, the sum of estimated and observed container movement time was calculated, and the percentage error variation was estimated with respect to the sum of observed container movement time. Handling activities taken into account were: vessel loading and/or unloading time; quay/yard crane idle time; shuttle waiting time; shuttle transfer time; reach stacker stacking time; reach stacker idle time; gate in/out waiting time. Such an analysis could be insightful for understanding if the modelling approach may depend on the specific handling equipment. In other words, a simpler modelling approach (e.g. sample mean) might turn out to be effective enough to simulate reach stackers activity time, but not to simulate cranes activity time.

Starting from the previous estimated values, an aggregate indicator was estimated by calculating the average error of each type of handling equipment weighted with respect to the number of activities in which the handling equipment is involved.

Since the output of a random variable model may be considered a realization of a stochastic process (the time associated to each single activity is the realization of a random variable), the values used for calibration are obtained by determining the average of 25 simulations (see Law and Kelton, 2000, about the "replication/deletion approach" for calculating the number of simulations required to obtain an estimate of the sampling average with a fixed interval of reliability).

The results in terms of average absolute percentage estimation error are reported in table 17. The use of sample mean handling models does not produce good results in terms of single container movement time estimation. Average percentage estimation error is greater than 29%, and differentiation among container type does not seem to improve models goodness of fit.

Better results were obtained in terms of handling equipment activity time estimation. Aggregating all the equipments, average percentage estimation errors exceed 11%; analyzing single equipment, average percentage estimation errors vary substantially from 13% for mobile harbor crane to 10% for gantry cranes, and to 5% for reach stackers. The differentiation among container type reduces estimation errors, and seems to be more effective for mobile harbor cranes and for gantry cranes.

Results obtained using random variable handling models are much more significant.

As regards single container movement time estimation, only using the RVCT handling models the absolute percentage estimation error is acceptable (>11%); in all other cases the estimation errors are about 30%.

As regards handling equipment activity time estimation, average absolute percentage error significantly decreases down to 6% with the RVU handling model, and down to about 3% with random variable container type (RVCT) handling models. Analyzing single equipment, average percentage errors shows the same trend of the aggregate indicator. For the mobile harbor crane and for the gantry crane RVU models results show an average errors of 6%-8%; while for reach stacker the estimation error is about 3%. Noteworthy results are obtained differentiating container type.

Table 17: Average absolute percentage estimation error: estimation sample.

Handling model	*Absolute percentage estimation error*				
	Container	*Handling equipment*			
		Mobile harbor crane	*Gantry crane*	*Reach stacker*	*All*
Sample Mean Undifferentiated (SMU)	30.8%	15.8%	12.6%	5.9%	13.2%
Sample Mean Container Type (SMCT)	29.3%	13.3%	10.6%	4.9%	11.0%
Random Variable Undifferentiated (RVU)	28.5%	7.8%	6.2%	2.9%	6.5%
Random Variable Container Type (RVCT)	11.2%	3.6%	2.9%	1.4%	3.0%

In conclusion, if the aim is to simulate handling equipment performances it can be deduced that cranes should be better simulated through random variable models and differentiation among container type is advisable, whereas reach stackers activity time can be effectively estimated through sample mean model, even without differentiating container type. If the aim is to simulate container movement time, there is no alternative to random variable modeling approach and differentiation among containers is mandatory.

In figure 1 cumulative absolute percentage estimation error variation is reported. Regarding the handling equipment indicator, the great variability of the phenomenon observed produces absolute estimation errors for sample mean models lower than 10% only for 25% of the handling equipment simulated, while for random variable models the absolute estimation error is always lower than 10% and for the RVCT this value is lower than 5% for 75% of the handling equipment simulated. If the aim of the simulation is to estimate container movement, the only suitable handling model is the RVCT one: only for this model is the absolute estimation error of the container operation time lower than 10% for 45% of the observations, and lower than 15% for over 60% of the observations. By contrast, for over 80% of the observations the absolute estimation error is lower than 30%. As can be seen in figure 1, the other models (SMU, SMCT and RVU) produce unacceptable absolute estimation errors for the purposes of the simulation.

From the model validation results we may obtain the following application guidelines. Results differ according to the handling models used; sample mean models could be used for estimating handling equipment indicator, with absolute percentage errors of 11%-13%; on using random variable handling models for estimating handling equipment indicator, absolute percentage errors decrease to 3%-6%. To estimate container movement performance (container indicator) only the RVCT handling models can be used (average absolute percentage estimation error more than 11%).

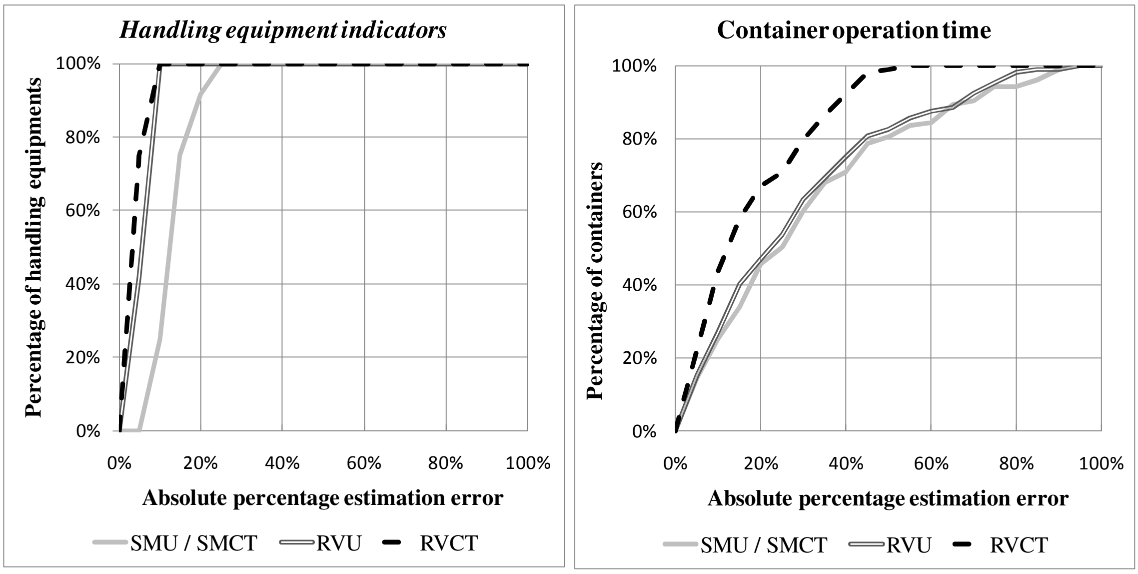

Figure 1: Cumulate absolute percentage estimation error variation.

5. Conclusions

In this paper container terminal handling equipments were modeled, with three main issues being addressed:

a. estimation of mean and standard deviation of activity time duration for different handling equipment and for different container types;
b. estimation of models for three handling equipment types (mobile harbor cranes, gantry cranes, reach stackers) and for different container types (undifferentiated, 20 feet, 40 feet, empty, full….);
c. effects on simulation of different hypotheses regarding (i) the approach to estimating handling time duration (sample mean vs random variable estimation), (ii) the level of aggregation of handling activities (e.g. vessel loading vs explicit simulation of elementary activities sequence), (iii) the segmentation of container type.

As regards point (a), our results allow the differences between activity time duration to be determined if different aggregation hypotheses are made for handling activity and/or container type. For instance, whether and to what extent an activity can be subdivided into several elementary activities, whether and how to distinguish container type. Sample mean values and standard deviations show that non-negligible differences can be observed and bear out the need for modeling handling activities through random variables. Particular care should be paid to container type, to the correct identification of elementary activities involved, and to those activities which stack containers in different tiers.

As regards point (b), calibration results enrich the existent state of art, give some insights on the best calibration approach (moment, maximum likelihood), highlight a family of suitable distribution functions to simulate handling equipment time duration and define the best-performing distribution functions for each handling equipment and each container type. >From a statistical point of view, the maximum likelihood estimation approach appears to perform best, while Normal, Gamma and Weibull distribution functions proved statistically significant to interpret handling activity time duration. In particular, the Gamma random variable leads to better goodness of fit for all handling activities and for all container types involved. The whole set of distribution functions (and of their parameters) allows different simulation models to be implemented with changes in activity aggregation and container type.

As regards point (c), some application guidelines may be drawn, with results differing according to what we want to simulate. If the focus is to simulate handling equipment time duration, both sample mean and random variable estimation can be pursued. Although sample mean models could be used for estimating handling equipment indicator, greater average absolute percentage errors must be accepted (11% to 13%) with respect to random variable handling models that have absolute percentage errors varying from 3% to 6%.If single container trip time (container indicator) is to be simulated, only *Random Variable Container Type* handling models should be used. In this case, average absolute percentage estimation error is about 11%, while about 30% for the other approaches.

Finally, the obtained results can be easily implemented in any terminal simulation model.

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