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UNCTAD Monographs on Port Management

A series of monographs prepared for UNCTAD in collaboration with the International Association of Ports and Harbours (IAPH)

Monograph No.6

MEASURING AND EVALUATING PORT PERFORMANCE AND PRODUCTIVITY

by

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Director
Antwerp Port Engineering and Consulting

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INTRODUCTION TO THE SERIES

In the ports of industrialized countries, operating systems and personnel development are based on skills acquired through experience, on emulation of other industries and on the innovation which is easily undertaken in advanced industrial environments. These means are generally lacking in developing countries and port improvements occur only after much deliberation and often through a process of trial and error. Some means is required by which ports in developing countries can acquire skills that are taken for granted in countries with a long industrial history, or can learn from the experience of others of new developments and how to meet them.

Formal training is one aspect of this, and UNCTAD has devoted considerable effort to developing and conducting port training courses and seminars for senior management and to preparing training materials to enable middle-management courses to be conducted by local instructors. It was felt that an additional contribution would be the availability of clearly written technical papers devoted to common problems in the management and operation of ports. The sort of text that will capture an audience in the ports of developing countries has to be directed at that very audience, and very few such texts exist today.

Following the endorsement of this proposal by the UNCTAD Committee on Shipping in its resolution 35 (IX), the UNCTAD secretariat decided to seek the collaboration of the International Association of Ports and Harbours, a non-governmental organization having consultative status with UNCTAD, with a view to producing such technical papers. This series of UNCTAD Monographs on Port Management represents the results of this collaboration. It is hoped that the dissemination of the materials contained in these monographs will contribute to the development of the management skills on which the efficiency of ports in developing countries largely depends.

A. BOUAYAD
Director
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FOREWORD

When UNCTAD first decided to seek the co-operation of the International Association of Ports and Harbours in producing monographs on port management, the idea was enthusiastically welcomed as a further step forward in the provision of information to managements of ports in developing countries. The preparation of monographs through the IAPH Committee on International Port Development has drawn on the resources of IAPH member ports of industrialized countries and on the willingness of ports in developed countries to record for the benefit of others the experience and lessons learnt in reaching current levels of port technology and management. In addition, valuable assistance has been given by senior management in ports of developing countries in assessing the value of the monographs at the drafting stage.

I am confident that the UNCTAD monograph series will be of value to managements of ports in developing countries in providing indicators towards decision-making for improvements, technological advance and optimum use of existing resources.

The International Association of Ports and Harbours looks forward to continued co-operation with UNCTAD in the preparation of many more papers in the monograph series and expresses the hope that the series will fill a gap in the information currently available to port managements.

C. Bert Kruk
Chairman
Committee on International
Port Development
IAPH

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1. Introduction

1. In the past 20 years a significant number of studies, reports and conferences have looked into the subject of port performance and productivity. Generally speaking, their outcome left most interested parties rather unsatisfied, if not frustrated. Such a state of affairs cannot be explained by a mere failure of the authors to treat the subject competently. In fact the challenge taken up by anyone wanting to analyse port performance is most formidable, as a result of the combination of the following factors:

(a) The sheer number of parameters involved;

(b) The lack of up-to-date, factual and reliable data, collected in an accepted manner and available for publication or divulgation;

(c) The absence of generally agreed and acceptable definitions;

(d) The profound influence of local factors on the data obtained;

(e) The divergent interpretations given by various interests to identical results.

2. It is in this respect quite revealing that some major world ports manage to publish monographs and reports on "productivity in ports" without mentioning a single factual performance or productivity measure or figure.

3. The principal objective of this monograph is to attempt to: (a) arrive at a synthesis of the many past analyses carried out; (b) formulate generally acceptable definitions; and (c) propose commonsense interpretations of the results obtained and devise practical applications for the accumulated outputs.

4. In the given circumstances, it is of crucial importance to agree on a basic and common methodology. Hence in the following section an attempt will be made to formulate generally acceptable notions, before analysing the factors determining port performance and then suggesting methods of measuring and comparing through a generally agreed system of port statistics and indicators.

2. Measuring port performance and productivity

5. Ports are essentially providers of service activities, in particular for vessels, cargo and inland transport. The degree of satisfaction that is obtained on the basis of pre-set standards will indicate the level of port performance achieved. From the foregoing it is already obvious that port performance levels will be different depending on whether ships, cargoes or inland transport vehicles are served. Thus a port, at least in theory, may offer a very satisfactory service to vessel operators and at the same time be judged inadequate by cargo interests or inland transport operators (or vice versa). It is obviously more likely that poor performance will not be limited to one group of port users, but rather pervade all services offered by the port. The important lesson to learn from this is that port performance cannot be assessed on the basis of a single value or measure. In fact a meaningful evaluation of a port's performance will require sets of measures relating to:

(a) The duration of a ship's stay in port;

(b) The quality of the cargo-handling;

(c) The quality of service to inland transport vehicles during their passage through the port.

6. The complicating factor is the strong interrelationship that exists between the three sets and between the various performance measures in each. Thus it is virtually impossible and certainly inappropriate to study each of these in isolation. However because of the particular importance of the first two sets, and their dominant position with respect to the main port users (namely the ship operators), this monograph will mainly concentrate on a more detailed discussion of these first two.

2.1. The duration of the ship's stay in port

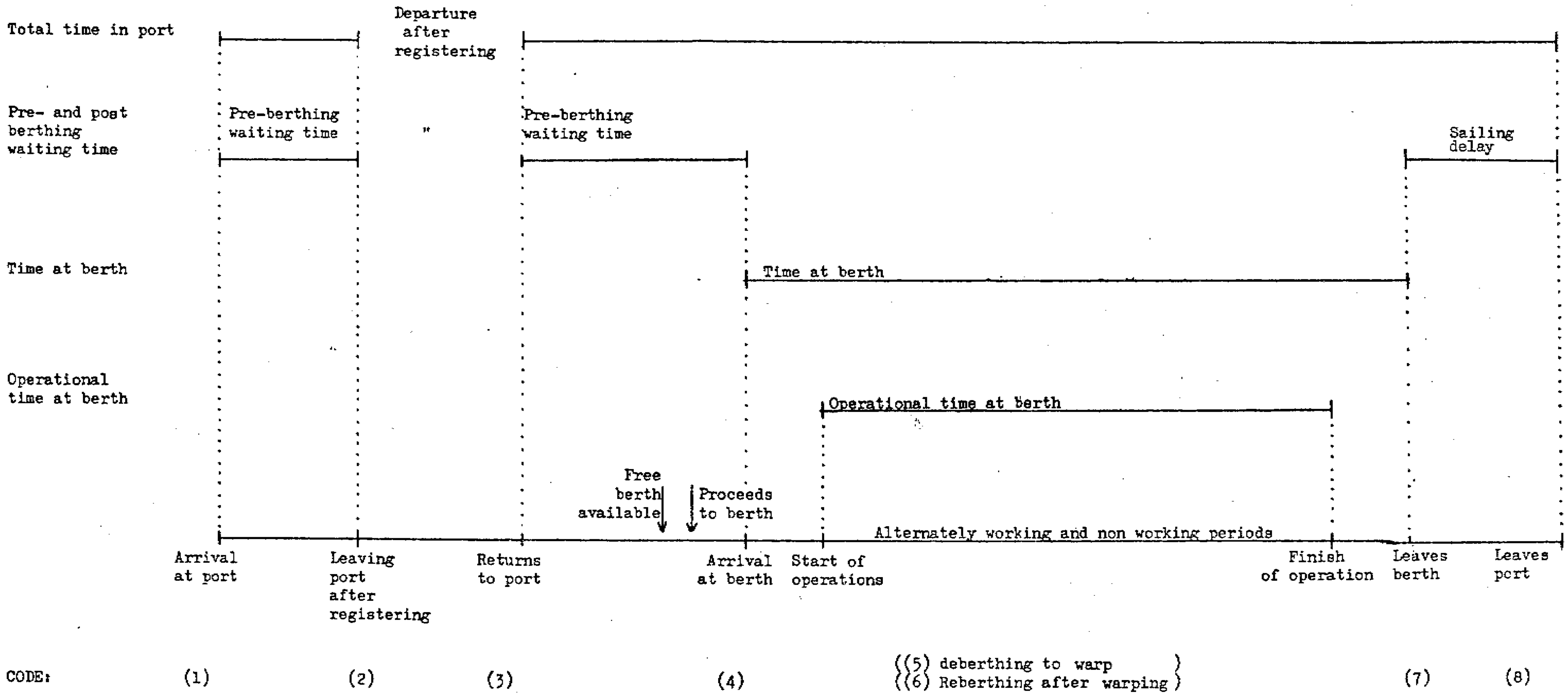
7. Figure 1 shows the standard stages of a vessel's passage through port. The first and foremost measure of "ship productivity" through a port will concern the "total turn-round time in port" of a given vessel on a given call (generally expressed in hours). However the total "time value" is not absolutely meaningful in itself but requires further substantiation. Thus a second measure presents total turn-round time in port as a function of cargo tonnage to be handled during that call, whilst a third measure must show the total turn-round time in port in the light of cargo composition (traditionally presented by main classes, e.g. bulk liquids, bulk solids, conventional general cargo, containerized cargo). In an economic analysis a special effort may be made to express the above-mentioned ship productivity values in monetary terms by duly taking into account the daily cost of the vessel in port (generally based on average values per type and age class, although considerable variations may exist from vessel to vessel type depending on flag, vessel management and conditions of acquisition).

8. Up to this point the "total turn-round time" in port has been examined without any breakdown of the "ship's time" periods as shown in figure 1. Although a reduction of any of these may improve the overall "productivity of the ship in port", at least two of these periods require special emphasis, namely the "ship's waiting time for a berth" and the "ship's time at berth". These two measures are particularly crucial in ports facing latent or acute port congestion, i.e. where ships have regularly to wait before berthing because all adequate service points are already occupied.

9. In the past a significant number of studies have examined the importance of both these periods, and more importantly their direct relationships. Thus figures 2, 3 and 4 present graphically the relationships which were theoretically established for general cargo facilities by the UNCTAD secretariat in its study Berth throughput: systematic methods for improving general cargo operations. 1/ The ratios on the basis of which these graphs are drawn are reproduced in table 1. It may be useful to point out that the results obtained are based on queueing theory formula with Poisson arrivals and exponential service times with first-come, first-served queue discipline. A number of subsequent analyses were carried out based on additional port information and resulted in the revised ratios contained in tables 2 and 3, whereby not only is a distinction made between break-bulk and specialized terminals 2/ but practical experience from ports is also incorporated. 3/

Figure 1

Break-down of ship's time in port



UNCTAD PORTS SECTION

UNDP PROJECT RAF/78/011

Source: "Manual on a uniform system of port statistics and performance indicators" (UNCTAD/SHIP/185/Rev.1).

FIGURE 2

Relationship between berth occupancy and ship waiting time: 2-berth case

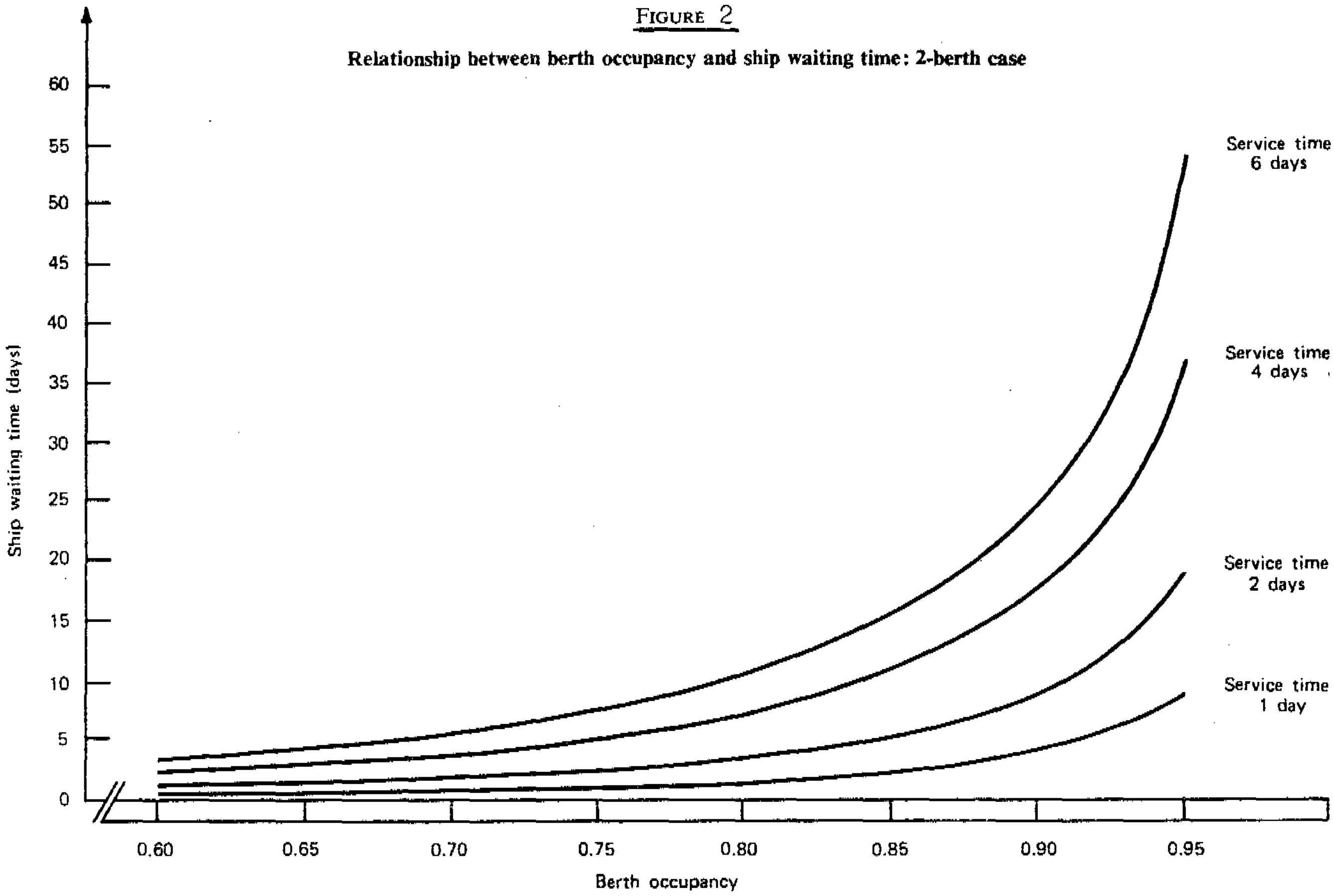


FIGURE 3

Relationship between berth occupancy and ship waiting time: 6-berth case

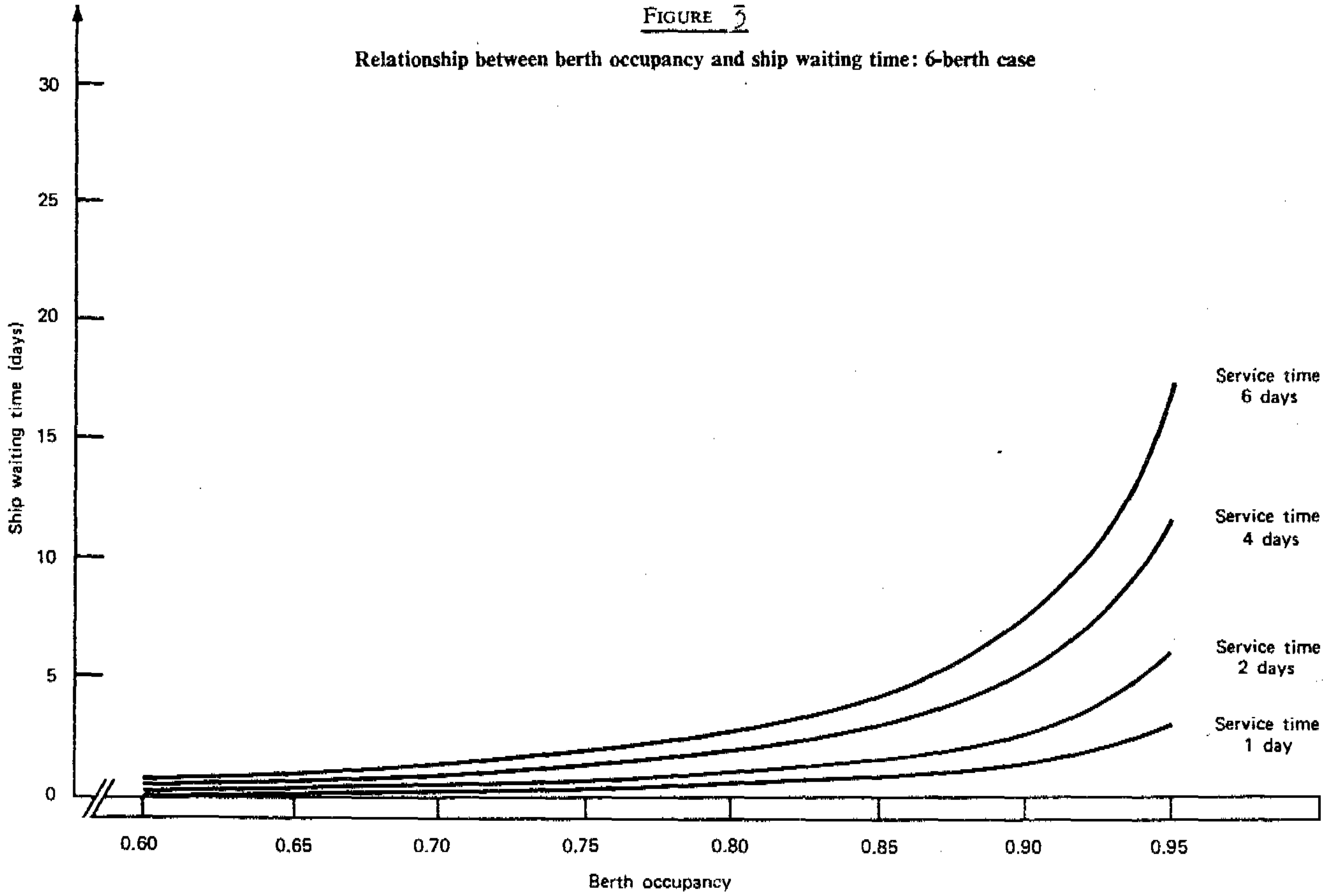
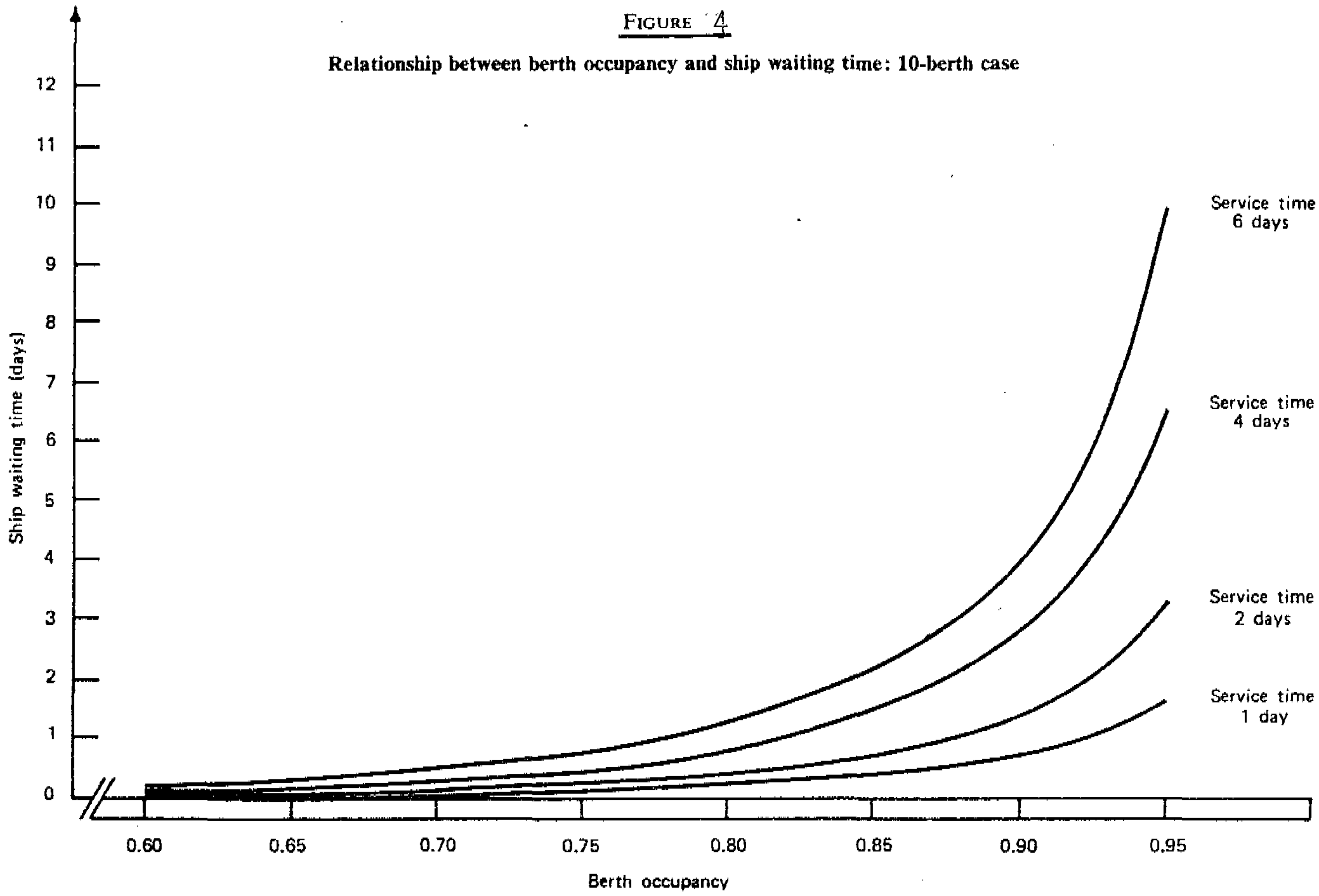


FIGURE 4

Relationship between berth occupancy and ship waiting time: 10-berth case



Source (figures 2, 3 and 4): Berth throughput: Systematic methods for improving general cargo operations (United Nations publication, Sales No. E.74.II.D.1).

Table 1

Queueing time/service time ratios

		Number of berthing points															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
	.050	0.053	0.003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.050
	.100	0.111	0.010	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.100
	.150	0.176	0.023	0.004	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.150
	.200	0.250	0.042	0.010	0.003	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.200
	.250	0.333	0.067	0.020	0.007	0.003	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.250
	.300	0.429	0.099	0.033	0.013	0.006	0.003	0.001	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.300
	.350	0.538	0.140	0.053	0.023	0.011	0.006	0.003	0.002	0.001	0.001	0.0	0.0	0.0	0.0	0.0	.350
	.400	0.667	0.190	0.078	0.038	0.020	0.011	0.006	0.004	0.002	0.001	0.001	0.001	0.0	0.0	0.0	.400
	.450	0.818	0.254	0.113	0.058	0.033	0.020	0.012	0.008	0.005	0.003	0.002	0.002	0.001	0.001	0.001	.450
	.500	1.0	0.333	0.158	0.087	0.052	0.033	0.022	0.015	0.010	0.007	0.005	0.004	0.003	0.002	0.002	.500
	.550	1.222	0.434	0.217	0.126	0.079	0.053	0.037	0.026	0.019	0.014	0.010	0.008	0.006	0.005	0.004	.550
	.575	1.353	0.494	0.254	0.151	0.097	0.066	0.047	0.034	0.025	0.019	0.014	0.011	0.009	0.007	0.005	.575
	.600	1.500	0.562	0.296	0.179	0.118	0.082	0.059	0.044	0.033	0.025	0.020	0.016	0.012	0.010	0.008	.600
Berth	.625	1.667	0.641	0.344	0.213	0.143	0.101	0.074	0.056	0.043	0.034	0.027	0.021	0.017	0.014	0.012	.625
Occupancy	.650	1.857	0.732	0.401	0.253	0.173	0.124	0.093	0.071	0.055	0.044	0.035	0.029	0.024	0.020	0.016	.650
	.675	2.077	0.837	0.468	0.301	0.209	0.152	0.115	0.090	0.071	0.057	0.047	0.038	0.032	0.027	0.023	.675
	.700	2.333	0.961	0.547	0.357	0.252	0.187	0.143	0.113	0.091	0.074	0.061	0.051	0.043	0.037	0.031	.700
	.725	2.636	1.108	0.642	0.426	0.305	0.299	0.178	0.142	0.115	0.095	0.080	0.067	0.058	0.049	0.043	.725
	.750	3.0	1.286	0.757	0.509	0.369	0.281	0.221	0.178	0.147	0.123	0.104	0.089	0.076	0.066	0.058	.750
	.775	3.444	1.504	0.899	0.614	0.451	0.347	0.276	0.225	0.187	0.158	0.135	0.117	0.102	0.089	0.079	.775
	.800	4.0	1.778	1.079	0.746	0.554	0.431	0.347	0.286	0.240	0.205	0.176	0.154	0.135	0.119	0.106	.800
	.825	4.714	2.131	1.311	0.917	0.689	0.543	0.441	0.367	0.311	0.267	0.232	0.204	0.181	0.161	0.145	.825
	.850	5.667	2.604	1.623	1.149	0.873	0.693	0.569	0.477	0.408	0.353	0.310	0.274	0.245	0.220	0.199	.850
	.875	7.0	3.267	2.062	1.476	1.132	0.908	0.751	0.635	0.547	0.478	0.422	0.376	0.338	0.306	0.278	.875
	.900	9.0	4.263	2.724	1.969	1.525	1.234	1.028	0.877	0.761	0.669	0.594	0.533	0.482	0.439	0.402	.900
	.925	12.333	5.926	3.829	2.796	2.185	1.782	1.497	1.285	1.122	0.993	0.888	0.802	0.729	0.668	0.614	.925
	.950	19.0	9.256	6.047	4.457	3.511	2.885	2.441	2.110	1.855	1.651	1.486	1.348	1.233	1.134	1.049	.950
	.975	38.999	19.252	12.708	9.451	7.504	6.211	5.291	4.602	4.068	3.642	3.295	3.006	2.762	2.553	2.373	.975

Source: Calculated by UNCTAD secretariat from queueing theory formula with poisson arrivals and exponential service times with first-come, first-served queue discipline.

TABLE 2

Waiting-time factor. Average waiting time of ships in the queue $M/E_2/n$ expressed in units of average service time

(Random arrivals, Erlang 2-distributed service time)

Utilization	Number of berthing points														
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
0.30	.32	.08	.03	.02	.01	—	—	—	—	—	—	—	—	—	—
0.31	.34	.09	.03	.02	.01	—	—	—	—	—	—	—	—	—	—
0.32	.35	.09	.03	.02	.01	—	—	—	—	—	—	—	—	—	—
0.33	.36	.09	.04	.02	.01	—	—	—	—	—	—	—	—	—	—
0.34	.37	.10	.04	.02	.01	.01	—	—	—	—	—	—	—	—	—
0.35	.39	.11	.04	.02	.01	.01	—	—	—	—	—	—	—	—	—
0.36	.41	.11	.04	.03	.02	.01	—	—	—	—	—	—	—	—	—
0.37	.43	.12	.05	.03	.02	.01	—	—	—	—	—	—	—	—	—
0.38	.44	.13	.05	.03	.02	.01	.01	—	—	—	—	—	—	—	—
0.39	.46	.13	.05	.03	.02	.01	.01	—	—	—	—	—	—	—	—
0.40	.48	.14	.06	.03	.02	.01	.01	—	—	—	—	—	—	—	—
0.41	.50	.15	.06	.03	.02	.01	.01	—	—	—	—	—	—	—	—
0.42	.52	.16	.06	.04	.02	.02	.01	.01	—	—	—	—	—	—	—
0.43	.54	.16	.07	.04	.02	.02	.01	.01	—	—	—	—	—	—	—
0.44	.56	.17	.07	.04	.03	.02	.01	.01	—	—	—	—	—	—	—
0.45	.59	.18	.08	.04	.03	.02	.01	.01	—	—	—	—	—	—	—
0.46	.61	.19	.08	.05	.03	.02	.02	.01	.01	—	—	—	—	—	—
0.47	.64	.20	.09	.05	.03	.02	.02	.01	.01	—	—	—	—	—	—
0.48	.66	.21	.09	.05	.04	.03	.02	.01	.01	—	—	—	—	—	—
0.49	.69	.23	.10	.06	.04	.03	.02	.01	.01	.01	—	—	—	—	—
0.50	.72	.24	.11	.06	.04	.03	.02	.01	.01	.01	—	—	—	—	—
0.51	.74	.25	.12	.07	.04	.03	.02	.02	.01	.01	.01	—	—	—	—
0.52	.78	.26	.13	.07	.05	.03	.02	.02	.01	.01	.01	—	—	—	—
0.53	.81	.28	.13	.08	.05	.04	.03	.02	.01	.01	.01	—	—	—	—
0.54	.84	.29	.14	.08	.05	.04	.03	.02	.01	.01	.01	.01	—	—	—
0.55	.88	.31	.15	.09	.06	.04	.03	.02	.02	.01	.01	.01	—	—	—
0.56	.91	.33	.16	.10	.06	.05	.03	.02	.02	.01	.01	.01	.01	—	—
0.57	.95	.35	.17	.11	.07	.05	.04	.03	.02	.02	.01	.01	.01	—	—
0.58	1.00	.37	.18	.11	.07	.05	.04	.03	.02	.02	.01	.01	.01	.01	—
0.59	1.04	.39	.19	.12	.08	.06	.04	.03	.02	.02	.02	.01	.01	.01	—
0.60	1.08	.42	.20	.13	.08	.06	.05	.04	.03	.02	.02	.01	.01	.01	.01
0.61	1.13	.44	.22	.14	.09	.07	.05	.04	.03	.02	.02	.02	.01	.01	.01
0.62	1.18	.47	.23	.15	.10	.07	.06	.04	.03	.03	.02	.02	.01	.01	.01
0.63	1.23	.49	.25	.16	.11	.08	.06	.05	.03	.03	.02	.02	.02	.01	.01
0.64	1.29	.51	.27	.17	.12	.09	.07	.05	.04	.03	.03	.02	.02	.01	.01
0.65	1.34	.53	.29	.19	.12	.09	.07	.05	.04	.04	.03	.02	.02	.02	.01
0.66	1.40	.60	.31	.20	.13	.10	.08	.06	.05	.04	.03	.03	.02	.02	.02
0.67	1.48	.63	.33	.22	.14	.11	.09	.06	.05	.04	.04	.03	.02	.02	.02
0.68	1.55	.66	.36	.23	.16	.12	.09	.07	.06	.05	.04	.03	.03	.02	.02
0.69	1.62	.70	.38	.25	.17	.13	.10	.08	.06	.05	.04	.03	.03	.03	.02
0.70	1.70	.72	.42	.27	.19	.14	.11	.09	.07	.06	.05	.04	.03	.03	.03
0.71	1.80	.78	.44	.29	.20	.15	.12	.10	.08	.07	.06	.04	.04	.03	.03
0.72	1.90	.83	.48	.31	.22	.17	.13	.11	.08	.07	.06	.04	.04	.04	.03
0.73	1.99	.87	.51	.34	.24	.18	.14	.12	.09	.08	.07	.05	.05	.04	.04
0.74	2.08	.93	.54	.36	.26	.20	.16	.13	.10	.09	.08	.05	.05	.05	.04
0.75	2.20	1.00	.59	.39	.28	.22	.17	.14	.11	.10	.09	.06	.06	.05	.05
0.76	2.31	1.08	.63	.42	.30	.24	.19	.15	.13	.11	.09	.07	.07	.06	.06
0.77	2.46	1.16	.68	.45	.33	.26	.21	.17	.14	.12	.11	.09	.08	.07	.07
0.78	2.59	1.23	.73	.49	.36	.28	.23	.19	.16	.13	.12	.10	.09	.08	.07
0.79	2.75	1.30	.79	.53	.40	.31	.25	.21	.17	.15	.13	.11	.10	.09	.08
0.80	2.95	1.40	.84	.57	.43	.34	.27	.22	.19	.17	.15	.13	.11	.10	.09
0.81	3.17	1.50	.92	.63	.47	.38	.30	.24	.21	.19	.16	.14	.12	.11	.10
0.82	3.45	1.70	.98	.68	.52	.42	.34	.27	.23	.21	.18	.16	.14	.12	.11
0.83	3.75	1.85	1.08	.74	.57	.47	.38	.31	.26	.23	.20	.18	.15	.14	.13
0.84	4.10	1.90	1.16	.81	.64	.50	.42	.34	.29	.26	.22	.20	.17	.16	.15
0.85	4.40	2.05	1.28	.90	.70	.56	.46	.38	.32	.29	.25	.22	.19	.18	.16
0.86	4.75	2.20	1.40	.98	.76	.61	.51	.42	.36	.32	.28	.25	.22	.20	.18
0.87	5.20	2.40	1.52	1.07	.84	.67	.56	.47	.40	.35	.31	.28	.25	.23	.20
0.88	5.60	2.60	1.68	1.16	.92	.75	.63	.52	.45	.39	.35	.31	.28	.26	.24
0.89	6.10	2.85	1.83	1.29	1.01	.83	.70	.58	.50	.44	.40	.36	.32	.29	.27
0.90	6.60	3.20	2.00	1.43	1.12	.92	.76	.64	.56	.49	.44	.40	.36	.33	.30

Source: Calculated by the UNCTAD secretariat.

TABLE 3

Average waiting time of ships in the queue $E_2/E_2/n$

(In units of average service time)

Utilization	Number of berthing points 1	2	3	4	5	6	7	8
0.10	.02	0	0	0	0	0	0	0
0.15	.03	.01	0	0	0	0	0	0
0.20	.06	.01	0	0	0	0	0	0
0.25	.09	.02	.01	0	0	0	0	0
0.30	.13	.02	.01	0	0	0	0	0
0.35	.17	.03	.02	.01	0	0	0	0
0.40	.24	.06	.02	.01	0	0	0	0
0.45	.30	.09	.04	.02	.01	.01	0	0
0.50	.39	.12	.05	.03	.01	.01	.01	0
0.55	.49	.16	.07	.04	.02	.02	.02	.01
0.60	.63	.22	.11	.06	.04	.03	.02	.01
0.65	.80	.30	.16	.09	.06	.05	.03	.02
0.70	1.04	.41	.23	.14	.10	.07	.05	.04
0.75	1.38	.58	.32	.21	.14	.11	.08	.07
0.80	1.87	.83	.46	.33	.23	.19	.14	.12
0.85	2.80	1.30	.75	.55	.39	.34	.26	.22
0.90	4.36	2.00	1.20	.92	.65	.57	.44	.40

Source: E. Page, *Queueing Theory in OR* (London, Butterworths, 1972) p. 155.

10. However, and although expected waiting times are lower in the revised ratios of tables 2 and 3, all the above-mentioned quantitative data bring out identical major conclusions, of which the most important can be summarized as follows:

(a) The expected waiting time ratio increases very rapidly with higher berth occupancy values. Thus a relatively small reduction of the time periods a vessel spends at the berth may have a considerable effect on the expected waiting time and hence on the productivity of the ship through the port. This effect is well illustrated in figure 5, where a limited improvement in cargo-handling performance leads to a substantial saving in ship turn-round time;

(b) The probability of waiting is much reduced for the same berth occupancy levels if the number of identical berths available is higher. Hence smaller ports may encounter a higher waiting time risk than larger ports even if the same occupancy values are achieved. This conclusion also raises the question of the significance of an optimal berth occupancy value which could be valid for all ports and which is often requested by port managers and ship operators at port conferences and seminars. In fact, does such an ideal utilization level exist?

(c) The optimal berth occupancy figure may well have a meaning for individual terminals or well-defined break-bulk berth groups, but even then it is unlikely that port managers will be in a position to provide this optimal number continuously and on a long-term basis. It is indeed not a realistic request, because both the very considerable traffic fluctuations and the indivisibility of port infrastructure investments militate against it. However it may ultimately be possible to retain a compromise solution, which could, for example, be based on an average minimum total cost in port, as shown in figure 6. It should be noted however that total cost in port has

FIGURE 5

Effect of reduction in discharging/loading time on turn-round time

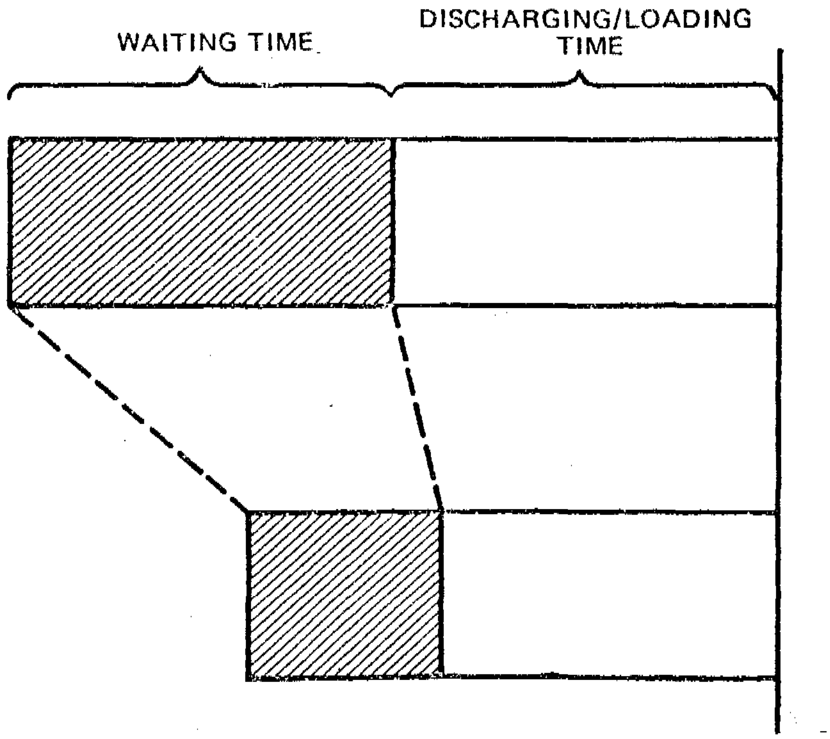
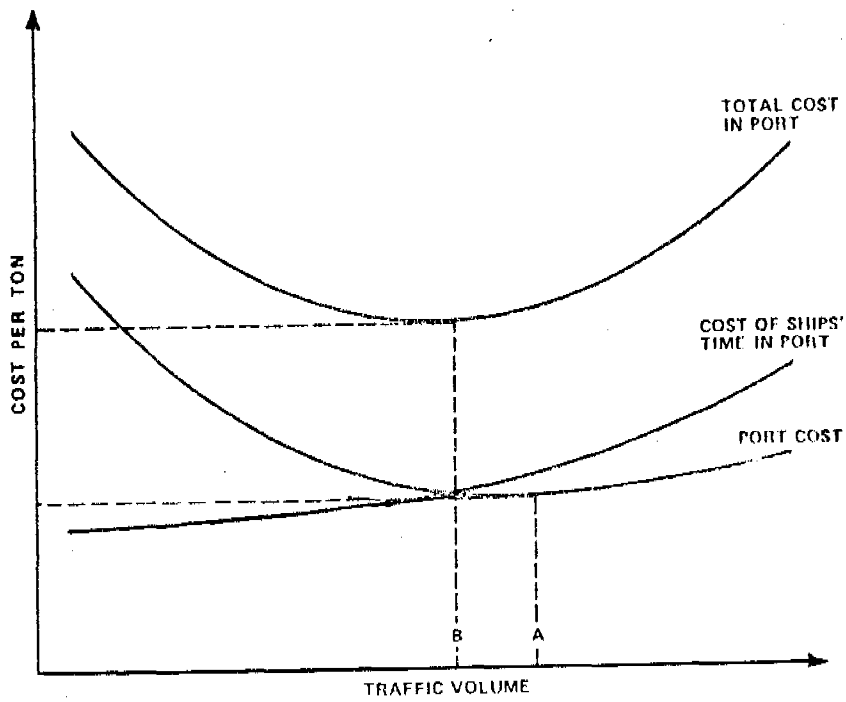


FIGURE 6

Variation of total cost in port with increasing traffic



Source: Berth throughput: systematic methods for improving port operations.

a minimum that is achieved at a much lower traffic volume than that leading to the lowest port cost. In fact this conclusion then points to the existence of a basic and essential contradiction between the interests of the ship operator and those of the port. The shipping lines will insist on immediate berthing, no waiting time and hence a larger number of berthing points than strictly necessary for present demand. The port will aim at reducing capital infrastructure as much as possible and at achieving the highest possible occupancy levels;

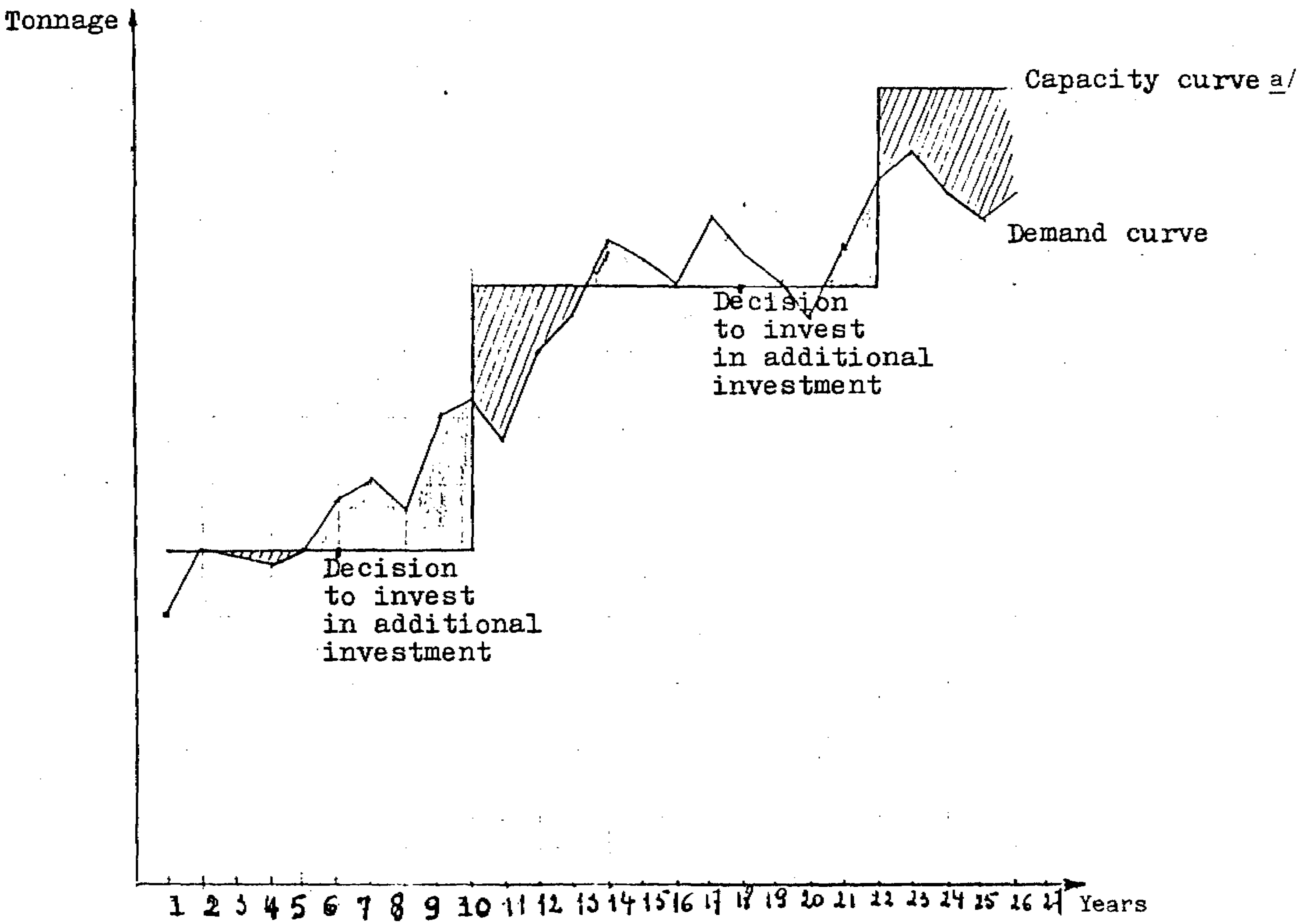
(d) From the foregoing, and in particular from the arguments set out under (c), it becomes evident not only that a high "productivity of the ship through port" can be achieved through better performance of the port during the various service stages (and in particular cargo-handling) but also that such higher "productivity of the ship through port" can be the result of a certain overprovision of facilities (for example berths as reserve capacity), a policy which to some is equivalent to the creation of overcapacity. It is certainly true that the borderline between the two is extremely vague and may actually move over time. This latter feature can be explained by the simultaneous fluctuation of demand (also in the short term) and the indivisibility of capacity (capacity in itself is a flexible value and varies with factors such as cargo-mix, operating conditions, vessel types and consignment sizes). 4/

11. Figure 7 schematically illustrates in a simplified graphic way this difficulty of matching port capacity and demand in the long term. The disequilibrium is likely to be even more pronounced in the short term. Moreover whenever traffic volumes are in excess of capacity, the port will be under very strong pressure from its main users to provide more capacity immediately, a demand which is obviously not easy to meet. Many ports in the industrialized world have therefore taken a policy decision to provide a certain margin of safety in capacity terms, which further helps to increase productivity and in turn enhances overall port capacity. However this safety margin is not free of cost, and most developing countries consider it inopportune to invest in such additional capacity when resources are scarce. Nevertheless, it should be noted that the extra cost of providing reserve facilities may be relatively minor in comparison with the port congestion charges and the penalties a country faces whenever port capacity no longer meets traffic demands.

12. In conclusion, then, measures of the duration of a "ship's stay in port" are vital indicators of the quality of the service offered to the major users of a port. It should be noted that identical values may be perceived quite differently by the various ship operators, depending on their priority requirements, and that their judgement of the quality of service offered may therefore greatly differ.

Figure 7

Matching capacity with demand



a/ Capacity is assumed unchanged in the short-term only to simplify presentation and to clarify the relationship with demand.

2.2. Performance measures for cargo-handling on board and on shore

13. The essential period "time at berth" is basically constituted by alternative working and non-working periods during which cargo-handling takes place. As a result, the performance of the cargo-handling operation will to alarge extent determine the quality of service to the ship and consequently deserves special analysis. To effectively measure the cargo-handling performance, two groups of indicators are required, namely:

Indicators of output;

Indicators of productivity.

14. The indicators of output provide information on the total quantity of work done in a particular period or on the tonnage handled in a stated time. In ports the most commonly used indicators of output are:

Berth throughput;

Ship output;

Gang output.

The latter two values are obviously also measures of productivity and efficiency, with the last one constituting the most frequently used indicator of productivity.

15. Berth throughput measures the total tonnage of cargo handled at a berth in a stated period. Berth throughput is usually expressed on a weekly, monthly or annual basis. It does not, however, provide an indication of how efficiently the facilities have been managed. Moreover, this measure only has significance if it is further differentiated by stipulating the type of cargo handled, the handling techniques used (e.g. grabs, conveyor belts, conventional gear, container handling equipment), the route followed (direct/or indirect route) and the units of measurement (weight tonnes, freight tonnes, measurement tonnes). It is basically a measure of "activity" on a facility.

16. Ship output measures give a clear indication of how good cargo-handling operations are. Nevertheless, these figures still require the same differentiation as mentioned for berth throughput. The more frequently used measures include:

Tonnes per ship working hour;

Tonnes per ship hour at berth;

Tonnes per ship hour in port.

Large differences between these values will indicate considerable time losses for the ship at the berth or in the port.

17. A simplified example may well illustrate the importance of comparing these three measures. Let us assume that a vessel arrived in port at 4 a.m., berthed at 5 a.m., started working at 8 a.m., finished operations at 6 p.m.,

left berth at 11 p.m. and left port at midnight, and that during her stay she handled a total of 1,000 tonnes of general cargo. The respective output measures would then be:

Tonnes per ship working hour: 1,000 tonnes/10 hours = 100 tonnes/hour;

Tonnes per ship hour at berth: 1,000 tonnes/18 hours = 55 tonnes/hour;

Tonnes per ship hour in port: 1,000 tonnes/20 hours = 50 tonnes/hour.

Many ship operators will also calculate the following:

Ship output per 24 hours in port: $\frac{\text{1,000 tonnes x 24 hours}}{\text{20 hours}}$ = 1,200 tonnes/ per 24 hours.

In this very simplified example it is obvious that the gap between 55 tonnes per hour at berth and the 100 tonnes per ship working hour points to waste of time at the berth, when the vessel is not being operated. Although this example does not permit the pinpointing of the exact reasons why the ship registered a considerable amount of non-operational time, the port traffic manager certainly should be motivated to investigate the underlying causes and take the necessary remedial action.

18. Another much used measure of output is gang output. This is the average quantity (tonnes) of cargo handled by a gang in a certain time interval, normally an hour. This then is the most significant value regarding the performance of labour, although once more the bare "tonnes per gang-hour" measure needs to be completed by explanatory data on such factors as the gang composition, the cargoes worked, the ship's configuration and many others before any valid conclusions can be arrived at. One more refinement certain analysts aim for is to express output in man/hours rather than gang/hours, thus eliminating the distorting factor "gang composition". It may also be worthwhile emphasizing that in container terminals, output is now measured in "containers per gross or net crane hour", as the notion of a gang in such operations is no longer a realistic one.

19. The indicators of cargo-handling productivity are different from the indicators of output, in that they actually present a ratio between the output achieved and the effort put in, expressed in monetary terms. This notion is very closely linked to that of cost-effectiveness, whereby less costly handling will be identified as handling that is more cost-effective. Very often port managers and consultants alike tend to be mystified by the difference between output and productivity, and particularly by the fact that increased production is not necessarily synonymous with improved productivity. Hence on a berth it is possible to handle more cargo by employing more men per gang, and more gangs per ship, and by using more equipment and/or storage space. However, although this greater effort will no doubt produce more output, it constitutes no guarantee of higher productivity (i.e. a more cost-effective operation). Table 4 presents a simple illustration of this sometimes paradoxical relationship. For example, in the present operations a gang of 20 dockworkers many only achieve an output of 40 tonnes per ship-hour, whilst the planned alternative would offer 75 tonnes per ship-hour (a gain of almost 90 per cent). However, the cost-effectiveness of such a change is questionable, as the cargo-handling cost per tonne would actually increase from $11.0 to $12.2. Only if the gain in ship's time in port is actually realized can such an alternative be considered cost-effective overall. 5/

Table 4

The paradoxical relationship between output and productivity in a port context

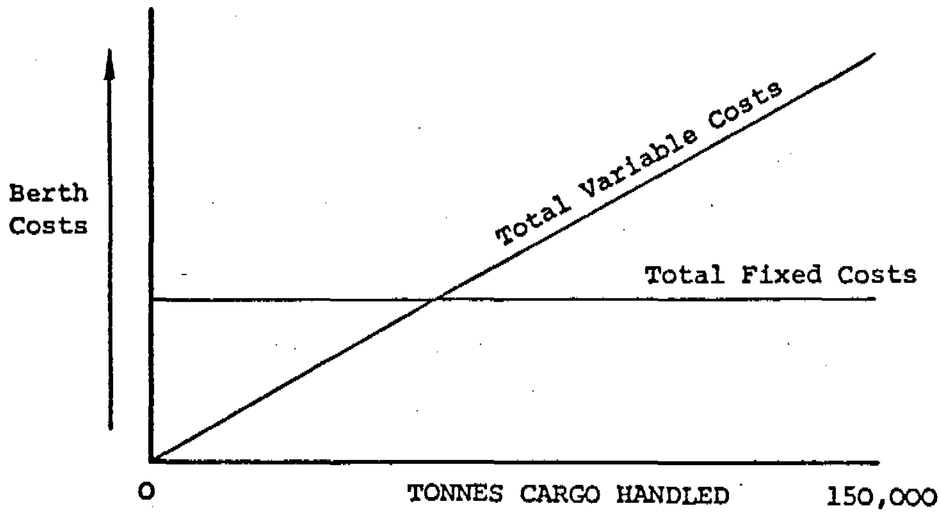
Present operations		Planned alternative
20	Dockworkers per gang	26
1	Average No. of cranes per gang	1.5
2	No. of gangs per ship	3
20	Output per gang-hour	25
40	Output per ship-hour	75
$100	Total crane cost per crane/hour	$100
$6	Total man-hour cost	$6
$200	Total crane cost per ship-hour	$450
$240	Total man-hour cost per ship-hour	$468
$440:40T= $11.00/tonne	Total cost per tonne	$918:75T= $12.24/tonne

20. This particular relationship also explains the tension between, for example, stevedores/terminal operators on the one hand and shipping lines/shipping agents on the other, when the daily plans with respect to cargo-handling operations are established. Invariably the ship interests will demand maximum gang and equipment allocation, whilst the stevedores will aim at cost-effectiveness in the light of the cargo distribution on board and the dominating hatch or bay.

21. Finally it is important to emphasize that although "least cost per tonne" may be a very realistic objective in most ports for most ships, certain circumstances may occur which could invalidate this basic assumption. In particular when a congestion wave hits a port or specialized port area, considerations of cost-effectiveness will no longer take precedence, and the port management's efforts will tend to boost output as much as possible. The potential total cost of congestion to a country may be such that cargo-handling costs become a relatively minor element.

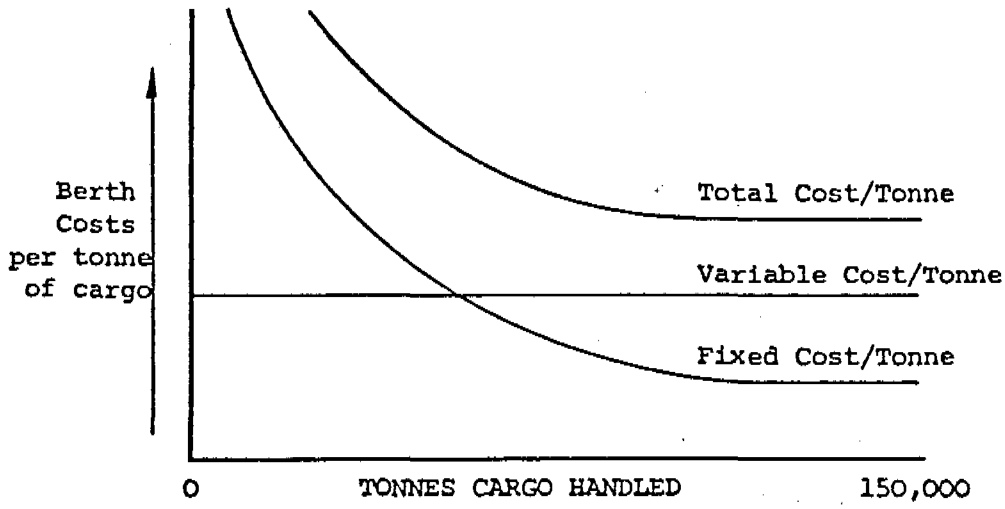
22. The measure of port productivity and cost-effectiveness also involves another important consideration. Up to this point all costs have been presented as homogeneous and identical in nature. However, to better understand the significance of productivity measures, a distinction between fixed costs and variable costs is essential. Fixed costs are independent of output (at least up to the full realization of a facility's potential), whilst variable costs increase as output rises. Hence when a port increases berth throughput on a facility, it will raise total berth costs (i.e. as a result of an increase in total variable costs and no variation in fixed costs). If these costs are, however, expressed per tonne of cargo handled, the situation becomes quite different. Total cost per tonne will then fall with a rise in throughput (due to a decrease of fixed costs per tonne and the unchanged variable costs per tonne). These two relationships are illustrated in figures 8 and 9 and explain the importance attached by port and terminal

Figure 8



Source: UNCTAD, Improving port performance - Management of general cargo operations (Cardiff, Drake Educational Associates Ltd., 1982).

Figure 9



Source: UNCTAD, Improving port performance ... .

managers to achieving full utilization of existing capacity, particularly when facilities are involved which are characterized by a large fixed-costs element (such as oil, ore or container terminals).

23. On general cargo berths (conventional, ro/ro, container or multi-purpose), labour costs generally represent a major proportion of total cost. As a result, a particularly significant productivity indicator is the one that relates manning with costs, i.e. "labour cost per tonne of cargo handled". However, it is critical to understand that in recent years the nature of the labour-cost element has changed from an exclusively "variable cost" type to a predominantly "fixed cost" one. 6/ This shift ultimately leads to higher productivity and lower employment levels and stimulates far-reaching mechanization. 7/ In any event, whenever labour costs become "fixed", they will force the port management, as do the other fixed costs, into a policy of full utilization of existing facilities to achieve maximum productivity.

2.3. The measures of occupancy

24. Already in the discussion of the "duration of the ship's stay in port" (see 2.1), and in particular of the relationship between service time and waiting times, attention was drawn to the meaning and importance of berth occupancy. It is a measure which is often misunderstood by port managers and as such it may constitute a particularly dangerous element in their decision-making. 8/ Berth occupancy effectively indicates the level of utilization of the berth facilities over a given time period (normally a week, a month or a year), based on an effective occupancy value calculated on an hourly or daily basis. Major differentials may thus result from the same base data, as shown in table 5.

Table 5

Calculation of berth occupancy values - illustration of the differential between a one-hour and a one-day recording (based on input information contained in annex I)

Date	One-hour basis			One-day basis		
	Berth 7	Berth 8	Berth 9	Berth 7	Berth 8	Berth 9
2.10	16.5	0.0	15.0	1	0	1
3.10	0.0	10.0	21.0	0	1	1
4.10	22.0	19.0	17.0	1	1	1
5.10	19.0	24.0	22.0	1	1	1
6.10	22.0	19.5	24.0	1	1	1
7.10	24.0	24.0	14.0	1	1	1
8.10	10.0	24.0	7.0	1	1	1
Total	113.5 h	120.5 h	120.0 h	6 d	6 d	7 d

Thus, in our example, berth occupancy can be:

On a one-hour recording: 70.2 per cent $(\frac{354\ h}{504\ h})$

On a one-day recording: 90.5 per cent $(\frac{19\ d}{21\ d})$

From the values contained in tables 1, 2 and 3 the importance of this differential is easy to deduce. It should be borne in mind that the more refined calculation is the more accurate one but not necessarily the one on which rules of thumb are based.

25. Overall berth occupancy rates are highly significant indicators, but they do not provide a direct answer to the underlying reasons for low or high occupation levels, nor to the productive value of the occupancy. Hence, it is necessary to subdivide the total available time at the berth into:

A "vacant berth" period;

An "occupied but not working" period;

An "occupied and working" period;

An "occupied but not workable" period. 9/

A simple example will illustrate the usefulness of this approach. Assuming that, in a three-berth conventional general cargo port, the overall berth occupancy rate is 85 per cent, broken down into a 25 per cent "occupied but not working" period, a 35 per cent "occupied and working" period and a 25 per cent "occupied but not workable" period, then it becomes clear that the 35 per cent "occupied and working" period is unsatisfactory and that the system faces gross inefficiency in the productive use of the facilities and allows far too much "not workable time" (i.e. probably because of lack of shift-work opportunities, or lack of willingness on the part of the shipowners to work in overtime). At the same time, 85 per cent berth occupancy with a mere three berths carries an extremely high waiting risk.

26. A first reaction may well be to consider the construction of new berths rather than to make an effort and to look for the more obvious causes, such as the unwillingness by the ship to operate in more costly working hours or the use of the berths for reasons other than purely commercial cargo-handling. Removing all such non-productive times would reduce the ports expected waiting time ratio from 1.34 to 0.04, 10/ a more than token gain in both ship's time and availability of berths.

3. Evaluating port performance and productivity

27. From the foregoing discussion on the measures of port performance and productivity, one fact emerges as of paramount importance: port performance and productivity cannot be determined by only one indicator or by a single all-encompassing value. The complexity of port operations, and in particular the interaction between various essential elements such as the efficiency with

which ships, berthing space, equipment and labour are utilized, make it compulsory to rely on a set of indicators if one wants to arrive at an accurate and meaningful evaluation of a port's performance.

28. The previously-mentioned indicators are often presented in a summary table of primary performance indicators by main cargo class. Figures 10 and 11 show examples of such summary tables for general cargo and container traffic in a hypothetical but realistic case-study port. Although these graphs do not necessarily provide the full explanation of potential performance and/or productivity shortcomings, they certainly point out significant inadequacies. To detect the precise causes of the observed shortfalls, port management must fall back on either secondary performance indicators or on actual on-the-spot observation and measurement. The use of secondary indicators will be illustrated in this section, in order better to understand the meaning of the essential measures of output and productivity, namely tonnes per gang-hour and tonnes per man-hour.

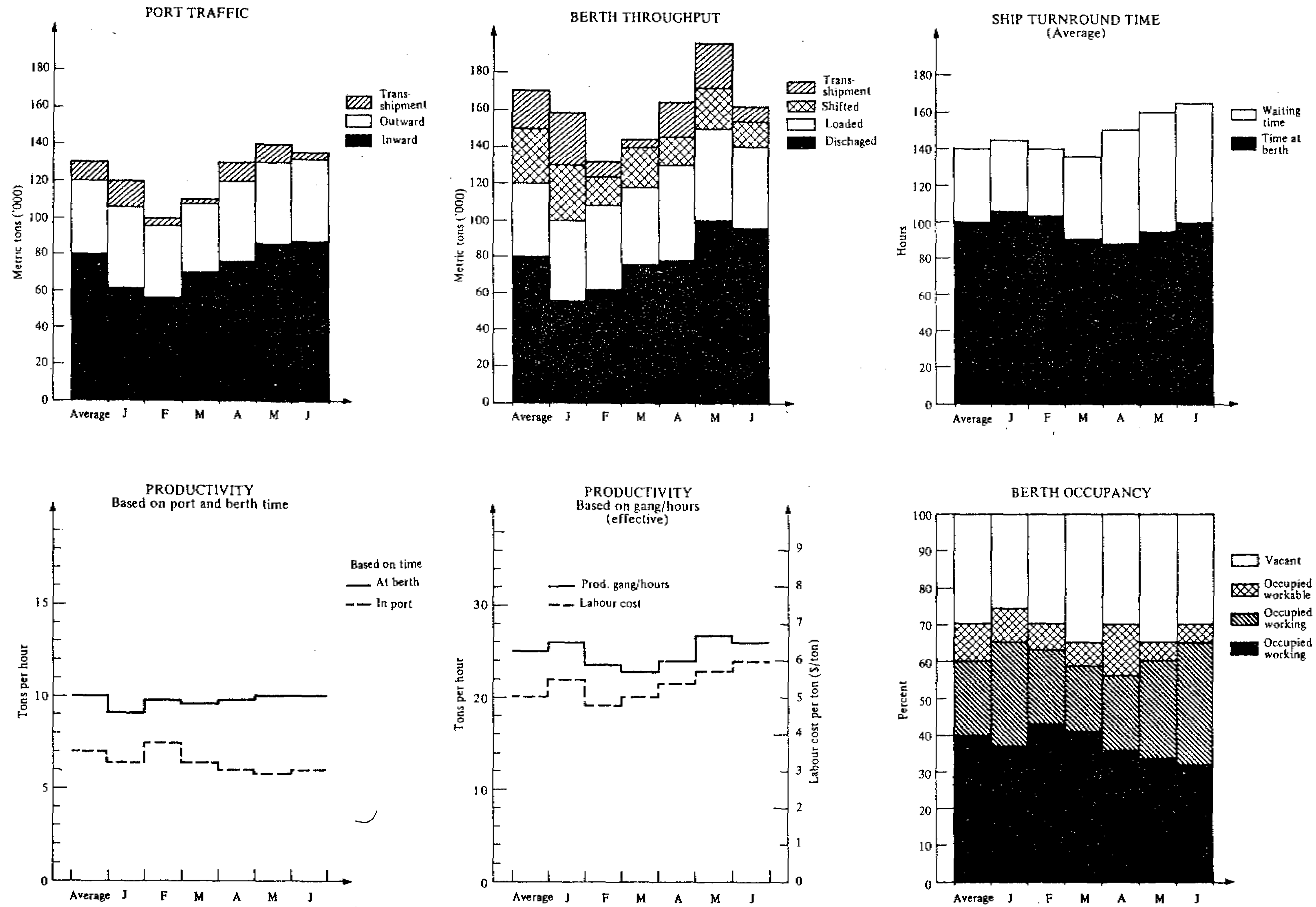
29. In the past, considerable effort has been spent in ports to determine the respective productivity levels of various operations. However, only very few major studies 11/ have looked into the main reasons for the obtained output figures. In this section a closer look will be taken at the recorded results and an effort will be made to determine the main underlying factors influencing these productivity values. The gross gang-hours show a particularly wide variation of the recorded values. The main reason for the skewed "normal curve" nature of the statistical data lies of course in the very large number of potential influencing factors, which all tend to make the end result practically "random". Figures 12 and 13 present productivity histograms developed for statistical data from the ports of La Valetta (Malta) and Valparaiso (Chile). 12/ Both are marked by an extremely wide spread of the tonnes per gang-hour recorded (from virtually one tonne to about 30 tonnes) and a very similar mean value of ± 13 tonnes per gang-hour. In fact the larger the sample size, the more the curve will resemble a skewed normal curve. This may not in itself be so surprising. Firstly, the number of factors strongly determining the gang-hour productivity is high and diverse, and secondly although the low values have a minimum threshold (when output = zero tonnes per gang-hour) there exists no upper limit (hence the skewed character of the curves).

30. The few studies that have examined the main determinant factors have particularly stressed the importance of the cargo handled and the type of ship in which they were carried. Contrary to the belief that a subdivision into liquid bulk, solid bulk and general cargo may well be sufficient, a far more detailed analysis of the cargo mix is required to grasp the essential differences in productivity. Figures 14 through 17 present for the Port of Karachi 13/ the respective productivity histograms for different general cargoes, such as wheat in bags, foreign general cargo imports, coastal general cargo imports (i.e. from the present Bangladesh, then East Pakistan) and rice in bags (exports). Table 6 then uses the average productivity values to calculate a global actual performance for the ship cargo-handling system, which comes out at about 50 tonnes/hour (calculated on hours that gangs are effectively provided).

Figure 10

PERFORMANCE INDICATORS
CONVENTIONAL BREAK-BULK

MONTH : JUNE 78

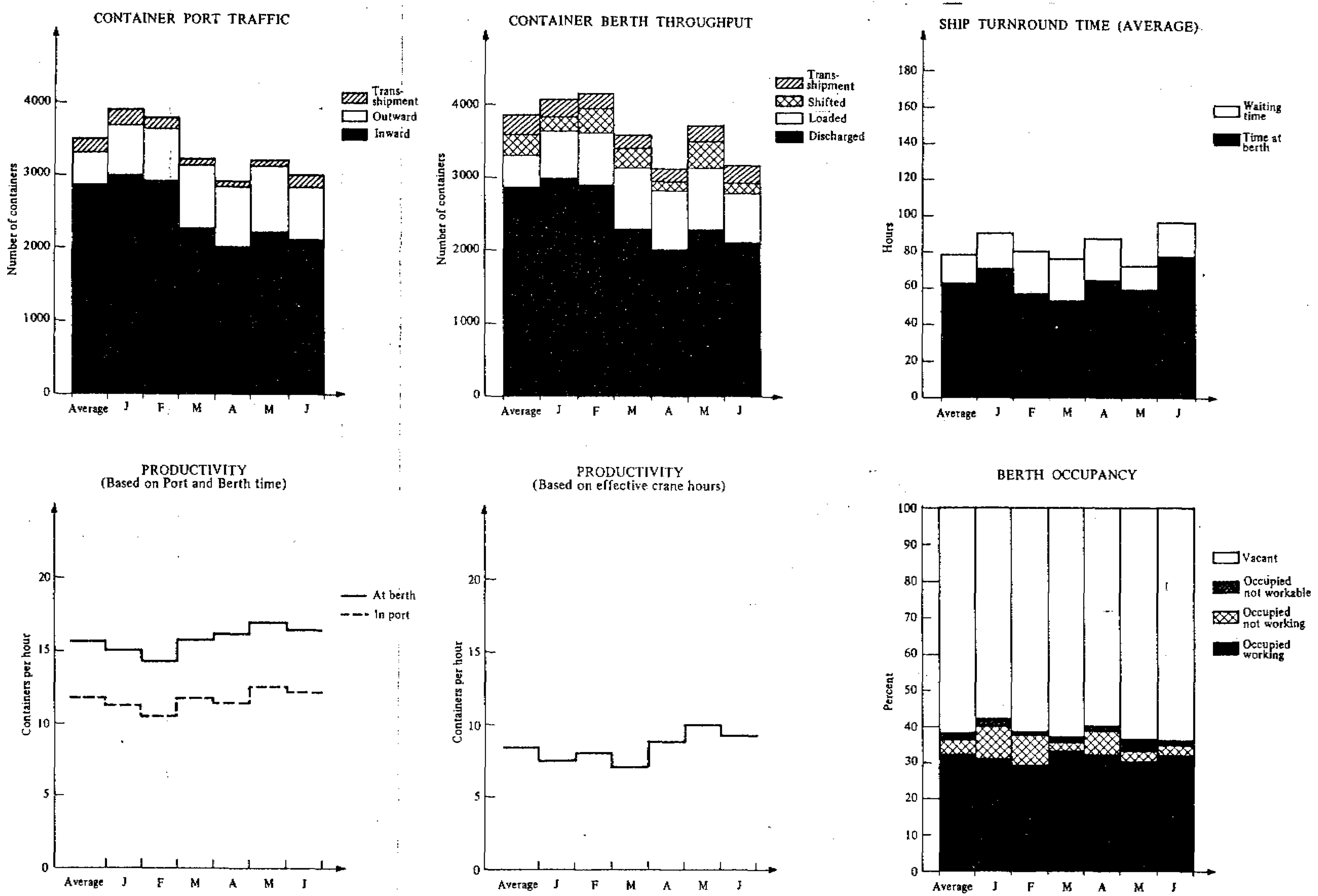


Source: "Manual on a uniform system of port statistics and performance indicators" (UNCTAD/SHIP/185/Rev.1).

Figure 11

PERFORMANCE INDICATORS
CONTAINERS

MONTH : JUNE 78



Source: "Manual on a uniform system of port statistics and performance indicators" (UNCTAD/SHIP/185/Rev.1).

FIGURE 12

Productivity histogram: general cargo (imports), Malta

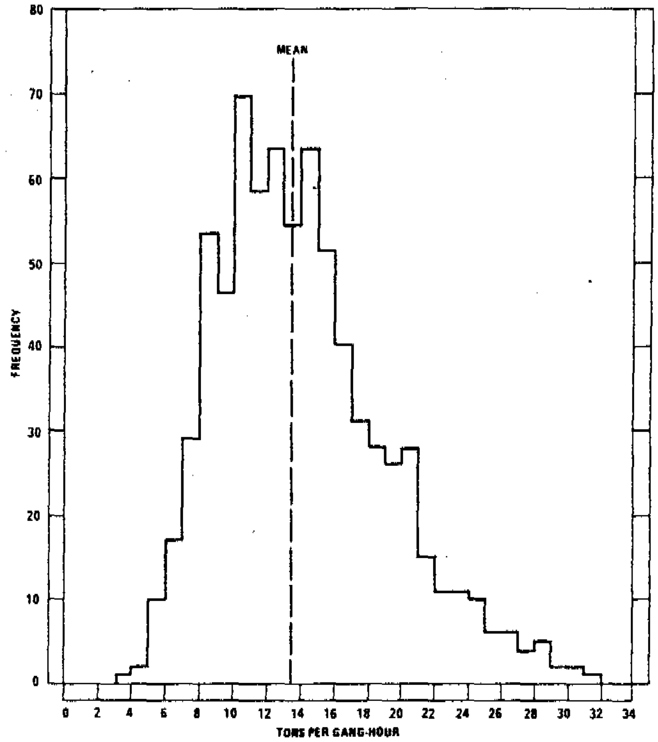
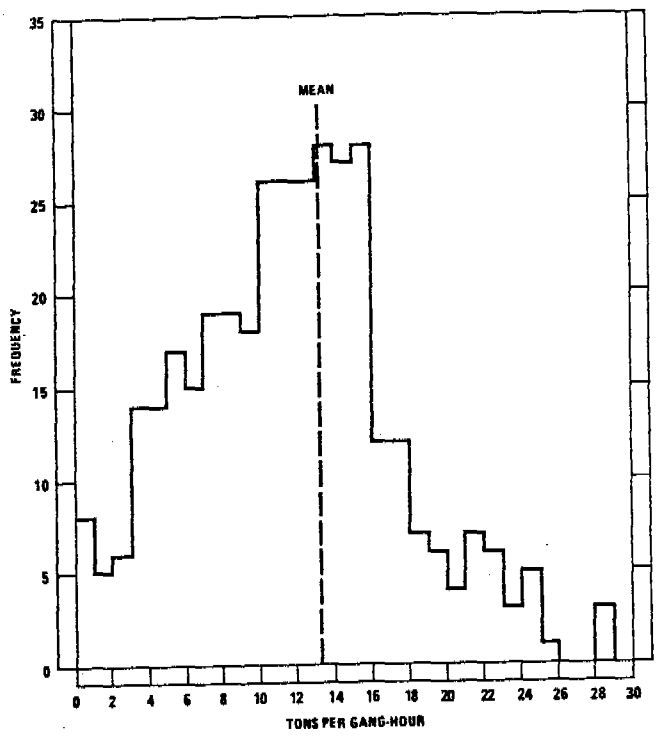


FIGURE 13

Productivity histogram: general cargo (imports), port of Valparaiso



Source: Berth throughput ... .

FIGURE 14

Productivity histogram: wheat in bags (imports), port of Karachi

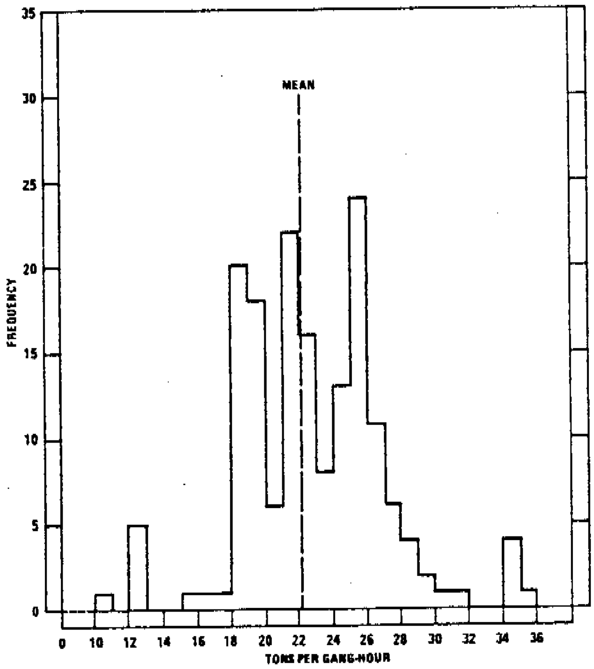


FIGURE 15

Productivity histogram: foreign general cargo mix (imports), port of Karachi

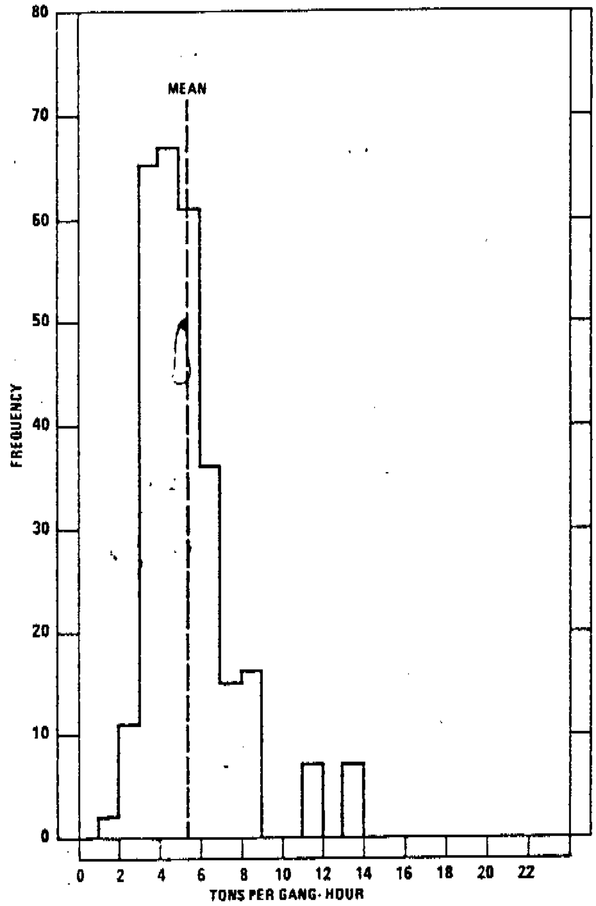


FIGURE 16

Productivity histogram: coastal general cargo mix (imports), port of Karachi

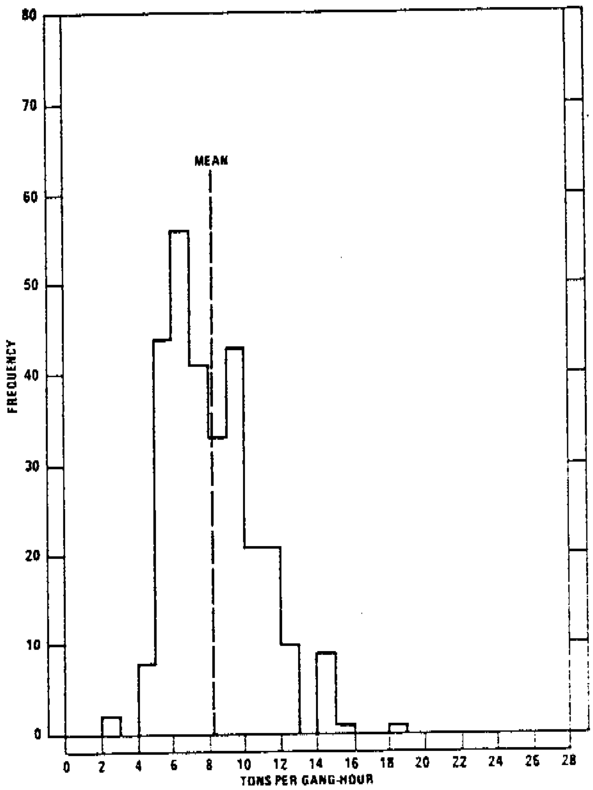
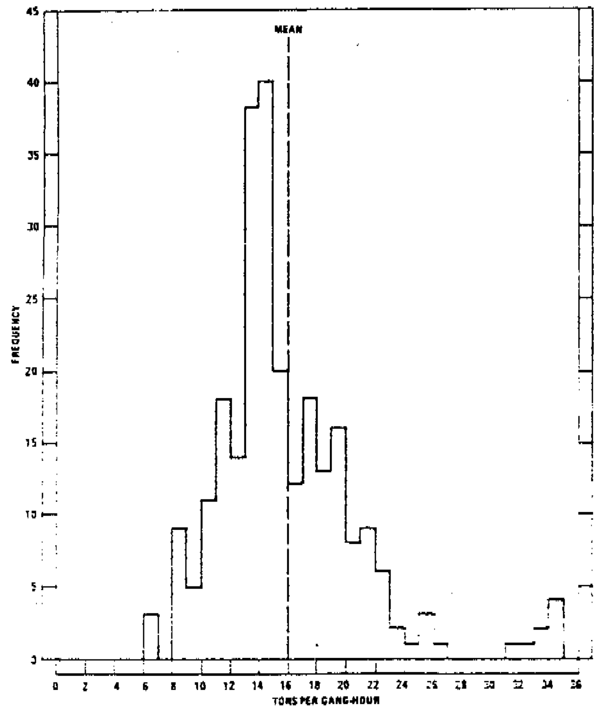


FIGURE 17

Productivity histogram: rice in bags (exports), port of Karachi



Source: Berth throughput ... .

Table 6

Calculation of the average hourly ship productivity, port of Karachi

Commodity class	Productivity tonnes per gang-hour (1)	Average number of gangs (2)	Percentage of total traffic (3)	Productivity: tonnes per ship-hour (4) = (1) x (2)	(5) = (3) ÷ (4)
Imports					
Wheat in bags	22.2	3.7	16.7	82.1	0.203
Coal and coke	11.6	5.2	3.1	60.3	0.051
Coastal general cargo	8.2	5.2	10.8	42.6	0.253
Foreign general cargo	5.4	5.2	10.2	28.1	0.363
Iron and steel products (including machinery)	7.5	5.2	11.4	39.0	0.292
Exports					
Cement in bags	16.3	4.7	5.4	76.6	0.070
Rice in bags	16.0	4.7	16.5	75.2	0.219
Bales of cotton/ textiles	10.7	4.7	7.6	50.3	0.151
General cargo	10.9	4.7	18.2	51.2	0.355
					1.957

Thus, the actual performance of the ship cargo-handling system = $\frac{100}{1.957}$ = 51.1 tonnes/hour.

31. This is a rather modest value, which raises questions with regard to the causes giving rise to a result that is not very satisfactory. The analyst will thus have recourse to secondary indicators, i.e. a set of additional data measuring the likely impact of each factor on output and productivity. From the multitude of such factors the most significant are as follows:

Size and type of vessel;
Total tonnage to be discharged/loaded per vessel call;
Consignment sizes (average tonnage per B/L);
Unit size of individual items;
Packing (type and quality);
Modal split of cargo movement;
Working method selected by stevedore and quay cargo-handling company (including selection of stevedoring tools);
Lifting gear and handling equipment used;
Size of the gang;
Weather conditions;
"Port of call" sequence in a given range.

32. Each of these factors merits further study and analysis, but this would no doubt require a separate publication. Suffice it to say that not only may the relative importance of these factors vary greatly from one call to another, but the factors themselves are practically all interdependent (e.g. the unit size's influence on productivity will differ with consignment size, and/or gang size, and/or modal split, etc. This influence may either be positive or negative, depending on the interaction between these elements).

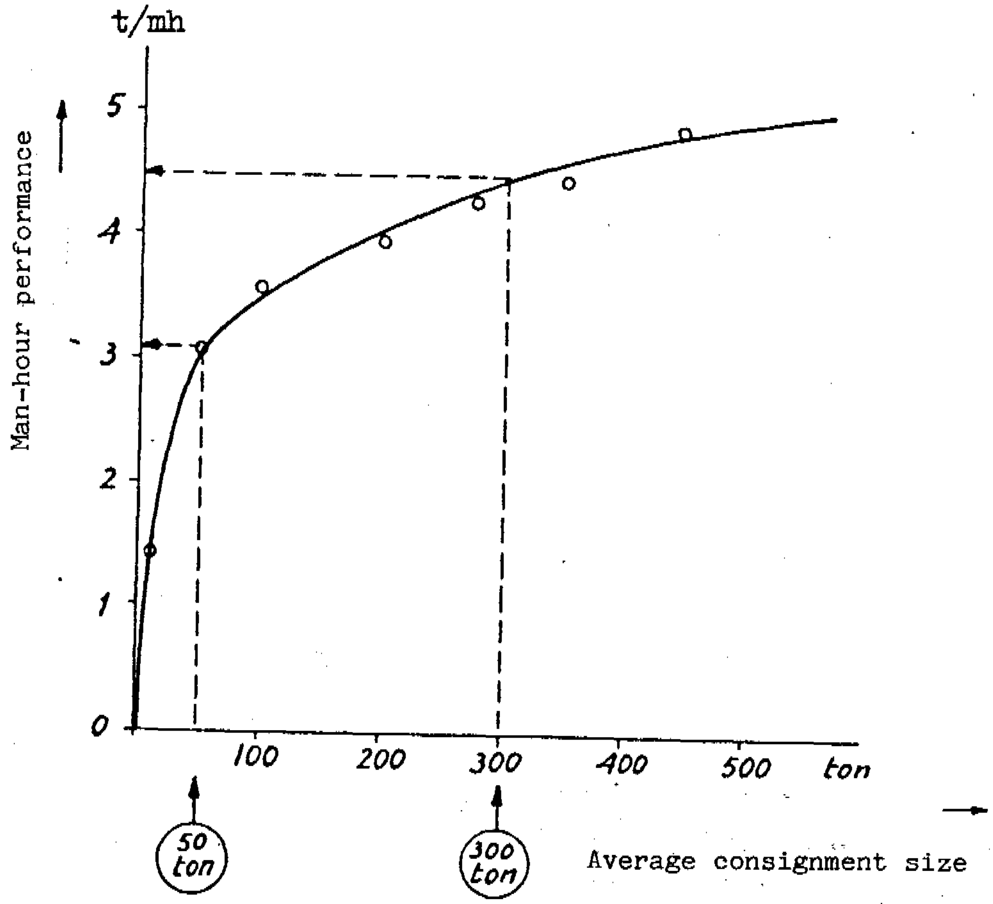
33. As a result only very experienced stevedores or terminal operators may predict with a certain measure of accuracy the expected gang-hour outputs, and only on condition that they have a full understanding of the precise context in which the operations will be carried out and have at their disposal the full details on ship and cargo. Even then, cargo-handling firms permanently monitor shift outputs and adjust the pre-planned working schedule accordingly.

34. In the previously cited report "Research into productivity" which was jointly published by the Ports of Rotterdam and Amsterdam in 1966, the above-mentioned significant determinants were closely monitored for 14 months (leading to 32,000 working reports covering 1,750,000 tonnes of general cargo) and an attempt was made to quantify the respective impact of major influences on man-hour productivity and performance. From this study material, it is worth presenting two relationships because of their importance and potential impact, namely the connection between consignment size (i.e. average tonnage per bill of lading) and man-hour output, and the relationship between modal split and man-hour output.

35. Figure 18 clearly shows that man-hour performance increases with consignment size. If the average consignment size grows from 50 to 300 tonnes, the expected man-hour output will improve from 3.2 tonnes to 4.5 tonnes (a 27 per cent gain). However, this example is only valid for bagged cargo. The gain for other commodities/packaging types may be either only marginal or on the contrary even more pronounced, and much will also depend on the other factors listed (e.g. size of ship, total tonnage to be discharged/loaded per call, etc.). The relationship between modal split and man-hour output is reflected in table 7. Again these figures require cautious interpretation. They are only valid for bagged cargo handled in Rotterdam/Amsterdam using conventional cargo-handling techniques and in a general port context such as existed in 1964 and 1965 in these two ports. However, the influence of the selected mode is undeniable, and in the example, bagged cargo handled directly into a barge offers a probability of a 26 per cent higher output than such cargo transferred into a transit shed. This is a significant difference, if not unexpected. It is most probably the result of short-term or longer-term imbalances in the various sub-parts of the berth system (i.e. it is quite common to find capacity differences between ship-handling, horizontal transfer, stacking, storage and delivery, and these differences will reduce not only total throughput capacity but equally short-run productivity).

Figure 18

Connection between consignment size and man-hour output (bagged cargo)



Source: "Research into productivity".

Table 7

Influence of modal split on man-hour performance (bagged cargo)

Modal split	Loading tonnes/man-hour	Discharging tonnes/man-hour
Lighter/barge	3.8	3.9
Transit shed	3.1	3.1
Closed truck/waggon	3.2	2.7
Quay apron	3.1	3.4
Open truck/waggon	-	3.7
Other	-	3.6
Weighted average	3.6	3.7

Source: "Research into productivity".

36. The discussion of output and productivity figures has been restricted up to this point to conventional general cargo handling. If the availability of reliable data for this type of cargo has already posed some problems, then these difficulties are much greater when it comes to obtaining similar information for container and roll-on/roll-off operations. Admittedly, newspaper reports and specialized magazines permanently feature productivity figures for container handling in ports, but these are merely ad hoc output rates, often quoted by the terminal operators out of context. Even if we accept that they try to present unbiased figures, operators subconsciously present maximum performances as long-term average values. This is precisely the reason why most of the published data are unreliable and inaccurate and grossly overestimate real outputs.

37. This situation is not going to improve in the near future, as for example the publication of fairly good-quality data on terminal performance by the International Association of Ports and Harbours (IAPH) will be discontinued at the request of its member ports. This is not such a surprising step if one considers that, quite apart from the extra effort involved in compiling the data and presenting them in a usable format, most ports are increasingly uncomfortable about disclosing their actual operating performance records. To a large extent this attitude can be explained by the importance of such data in commercial negotiations, particularly in the present competitive climate (very much characterized by over-supply in a retracting market). If anyone should doubt the importance of performance data in the "port competition battle", it may suffice to refer to the present "manipulation" of container traffic figures. Many ports calculate their container throughputs in such a way that an inflated total can be presented and thus a few places gained in the league table of the world's top container ports (even if this means double-counting, adding non-port-related traffic, etc.). Indeed a better position in that table may potentially attract new customers. The reference to maximum output rates (30 containers per hour per crane sounds almost low, as more and more operators claim rates in excess of 35 containers) has the same underlying logic. Container and roll-on/roll-off performance data must therefore be used with caution and not accepted at their face value.

38. The data presented in this paper come predominantly from shipping-line sources, cover long data collection periods and include important populations. They are therefore fairly reliable and constitute an acceptable basis from which certain conclusions can be drawn if the characteristics of the material are kept in mind. (The output rates are units per ship working hour or units per 24 hours at berth.) For example the data contained in tables 8 through 12 refer to two major shipping services using second- and third-generation vessels. Hence the overall results are biased, in that output rates on these vessel types are generally well above those recorded for converted container ships, semi-container ships, first-generation vessels, etc. However, a number of major points emerge:

(a) There are extremely wide variations in average gross productivity rates per hour around the mean:

	Mean output	Lowest output	Highest output
First period	24.5 cont/h.	9.9 cont/h.	45.5 cont/h.
Second period	26.6 cont/h.	13.0 cont/h.	45.1 cont/h.
Third period	24.6 cont/h.	10.6 cont/h.	48.2 cont/h.
Fourth period	33.3 cont/h.	11.8 cont/h.	48.2 cont/h.

(b) Differences in average gross productivities are much reduced by a tendency to work a higher proportion of berth time when hourly productivity is low and conversely to discharge and load the vessel for a much lower fraction of total berth time when the hourly productivities are high;

(c) The output per 24 hours at berth still varies considerably, notwithstanding the observation made in (b), but over a 7-year period the average 24-hour output is 467 containers, a rather mediocre result for large cellular container/ships.

The previously mentioned IAPH data put the performance figure per 24 hours for all containership types at 275 in 1979 and 353 in 1980, thus emphasizing the negative influence of smaller, or non-cellular, or non-adapted tonnage on productivity (see tables 13 (a) and 13 (b)).

39. Tables 8-12 can be used further in order to determine the impact on performance of such factors as:

The differential between crane average gross and crane average net values;

The average number of cranes used.

The analysis of "hourly gross crane average" is presented in figure 19, resulting in an hourly crane output rate varying from less than 8 containers per hour to a maximum of 28 containers per hour, with a mean value of 17.7 containers per gantry crane and per hour. Thus, long-term outputs per crane are decidedly less spectacular than certain terminal operators indicate in their marketing efforts. They are also below the figures quoted by major crane manufacturers, although the difference here can easily be explained as the normal deviation between rated equipment capacity and the actual performance which is negatively influenced by basic subsystem imbalances. 14/

Table 8

Performance data of leading container terminals, 1 April 1973-31 March 1975

Terminal (1)	Total number of containers in the sample (2)	Total number of ship calls in the sample (3)	Average gross productivity per hour (number of containers) (4)	Working time as per cent of berth time (5)	Throughput per 24 hours at berth (number of containers) (6)
A	88 710	85	19.8	79	375
B	12 656	30	26.2	80	502
C	40 237	116	22.6	71	383
D	18 726	36	28.6	62	426
E	106 408	134	45.5	60	656
F	30 143	67	27.7	76	505
G	49 516	53	17.4	77	322
H	13 320	29	40.9	45	445
I	114 856	80	43.1	42	431
J	26 762	67	29.4	41	290
K	107 838	77	39.3	47	443
L	24 132	28	9.9	95	226
M	37 304	123	36.3	59	516
N	93 612	71	11.1	89	237
O	104 130	138	41.0	47	465
P	104 136	96	14.3	85	290
Q	126 539	145	29.7	79	566
R	31 099	88	17.3	69	285
S	189 745	193	32.4	63	494
T	33 027	79	38.7	81	749
U	9 394	24	14.0	75	254
Total	1 362 290	1 759			

Source: Calculated on the basis of data provided by leading container consortia.

Table 9

Performance data of leading container terminals, 1 April 1975-31 March 1977

Terminal (1)	Total number of containers in the sample (2)	Total number of ship calls in the sample (3)	Average gross productivity per hour (number of containers) (4)	Working time as per cent of berth time (5)	Throughput per 24 hours at berth (number of containers) (6)
A	113 217	109	19.1	71	328
B	14 767	45	29.7	77	548
C	49 061	139	20.2	75	364
D	18 295	49	31.9	55	418
E	158 475	187	39.0	80	751
F	31 923	93	34.6	69	569
G	95 304	89	26.6	81	516
H	16 079	43	34.2	47	386
I	141 403	87	45.1	47	509
J	32 468	89	31.4	43	321
K	100 478	80	44.6	46	494
L	47 080	51	13.0	85	265
M	55 430	158	38.8	64	596
N	123 571	97	13.3	89	285
O	181 170	187	43.0	61	626
P	129 221	110	15.9	82	311
Q	175 585	183	31.0	72	546
R	39 994	136	17.4	66	275
S	259 604	264	35.2	62	527
T	112 450	200	38.7	81	755
U	16 608	43	22.6	62	339
V	13 527	33	30.0	71	512
W	-	-	-	-	-
X	36 859	42	18.3	62	272
Y	38 227	42	17.7	57	241
Z	48 018	58	18.5	59	260
Total	2 000 796	2 556			

Table 10

Performance data of major container terminals, 1 April 1977-31 March 1979

Terminal (1)	Total number of containers in the sample (2)	Total number of ship calls in the sample (3)	Average gross productivity per hour (number of containers) (4)	Working time as per cent of berth time (5)	Throughput per 24 hours at berth (number of containers) (6)
A	128 076	114	15.1	86	312
B	16 988	54	25.8	63	389
C	59 952	185	20.2	73	354
D	18 760	57	14.6	87	305
E	186 265	197	40.1	81	781
F	37 348	97	27.9	74	495
G	73 810	73	27.2	87	567
H	21 760	69	29.5	65	459
I	174 179	130	47.8	47	543
J	35 032	101	21.2	69	349
K	135 108	125	44.5	44	470
L	43 028	91	10.6	90	230
M	48 103	196	32.6	64	504
N	93 694	90	10.8	87	224
O	174 767	209	35.0	61	510
P	100 479	102	16.1	84	326
Q	166 660	209	30.5	79	576
R	26 745	89	14.1	74	249
S	257 123	225	26.0	63	391
T	122 259	212	41.6	81	811
U	14 525	85	16.2	58	224
V	33 198	111	32.1	54	416
W	30 057	29	21.7	62	323
X	44 267	56	23.3	60	338
Y	19 800	27	18.2	59	256
Z	48 018	58	18.5	59	260
Total	2 109 297	3 021			

Table 11

Performance data of major container terminals, 1 April 1979-31 December 1980

Terminal (1)	Total number of containers in the sample (2)	Total number of ship calls in the sample (3)	Average gross productivity per hour (number of containers) (4)	Working time as per cent of berth time (5)	Throughput per 24 hours at berth (number of containers) (6)
A	121 879	118	19.5	80	368
B	18 536	57	29.4	76	542
C	49 689	142	19.5	77	359
D	10 328	39	30.9	67	507
E	158 882	179	39.8	86	837
F	27 426	81	31.0	76	554
G	105 090	993	35.1	85	720
H	15 016	60	29.6	50	404
I	135 561	111	48.2	51	601
J	32 891	94	24.1	56	341
K	125 709	104	47.6	53	619
L	38 131	86	14.7	67	255
M	53 439	180	33.2	69	552
N	80 308	85	11.8	75	219
O	158 667	182	40.4	66	652
P	81 916	99	15.0	72	251
Q	136 597	196	32.7	82	639
R	20 462	80	12.5	68	210
S	263 911	288	34.0	73	592
T	137 612	200	39.8	87	827
U	11 289	61	25.2	46	330
V	42 778	151	36.5	61	537
W	42 654	35	42.9	57	590
X	36 364	51	29.8	50	375
Y	16 697	26	21.1	62	320
Z	43 150	58	31.3	46	356
AA	48 909	94	37.3	71	633
BB	2 362	14	26.1	65	437
CC	4 556	11	14.5	82	290
DD	14 868	18	30.7	93	678
Total	2 035 677	2 999			

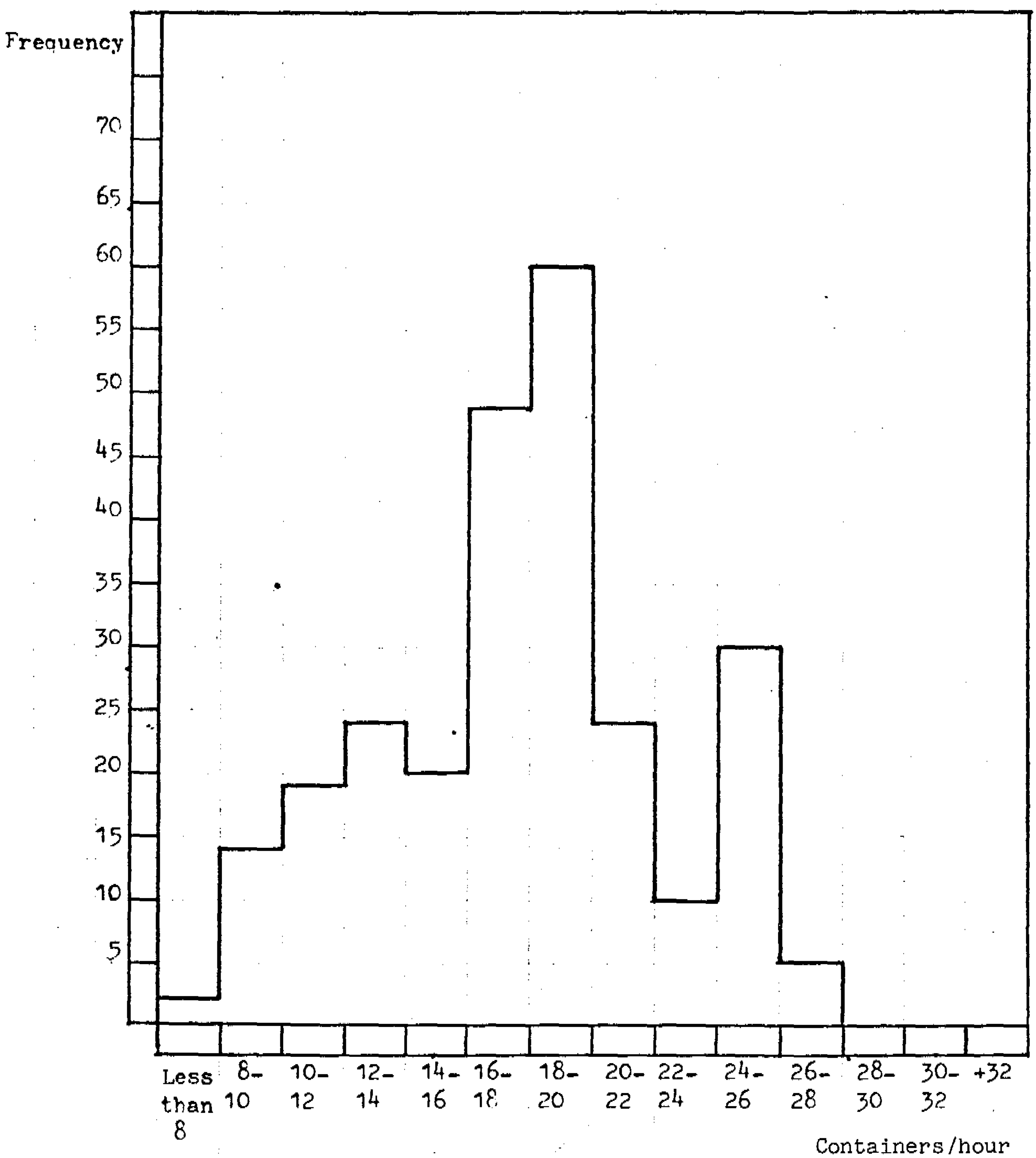
Table 12

Comparison of performance data of leading container terminals for three different time periods

Period (1)	Total number of containers in sample (2)	Total number of ship calls (3)	Average gross productivity (number of containers) (4)	Working time as percentage of berth time (5)	Throughput per 24 hours at berth (6)
1 Oct. 73 - 31 Mar. 75	1 362 290	1 759	24.5	75	442
1 Apr. 75 - 31 Mar. 77	2 000 796	2 556	26.6	70	444
1 Apr. 77 - 31 Mar. 79	2 109 297	3 021	24.6	70	415
1 Apr. 79 - 31 Dec. 80	2 035 677	2 999	33.3	71	565
TOTAL	7 508 068	10 335			
Average 1 Oct. 73 - 31 Dec. 80	-	-	27.3	71.5	467

Figure 19

Average crane output (gross)



Size of sample : 256 three-monthly terminal reports

Mean : 17.7

Source: Calculated on the basis of data provided by leading container consortia.

Table 13 (a)

Container terminal performance returns based on information published by IAPH (January-June 1978)

	Number of containers	Number of ships	Average number of containers handled per ship a/	Average output rate when working (per hour per ship)	Output per 24 hours
A	22 144	236	94	13.0	186
B	37 021	177	209	11.1	198
C	45 476	52	875	16.8	327
D	42 506	107	397	13.3	269
E	164 237	547	300	23.6	511
F	2 383	17	140	10.4	251
G	13 508	70	193	10.1	161
H	44 953	194	232	27.4	592
I	47 715	105	454	11.6	187
K	36 575	103	355	9.0	143
L	50 652	80	633	11.7	149
M	12 336	84	147	23.1	329
N	56 537	82	689	8.7	220
Total	576 043	1 854	311	-	275

a/ Including re-stows

Table 13 (b)

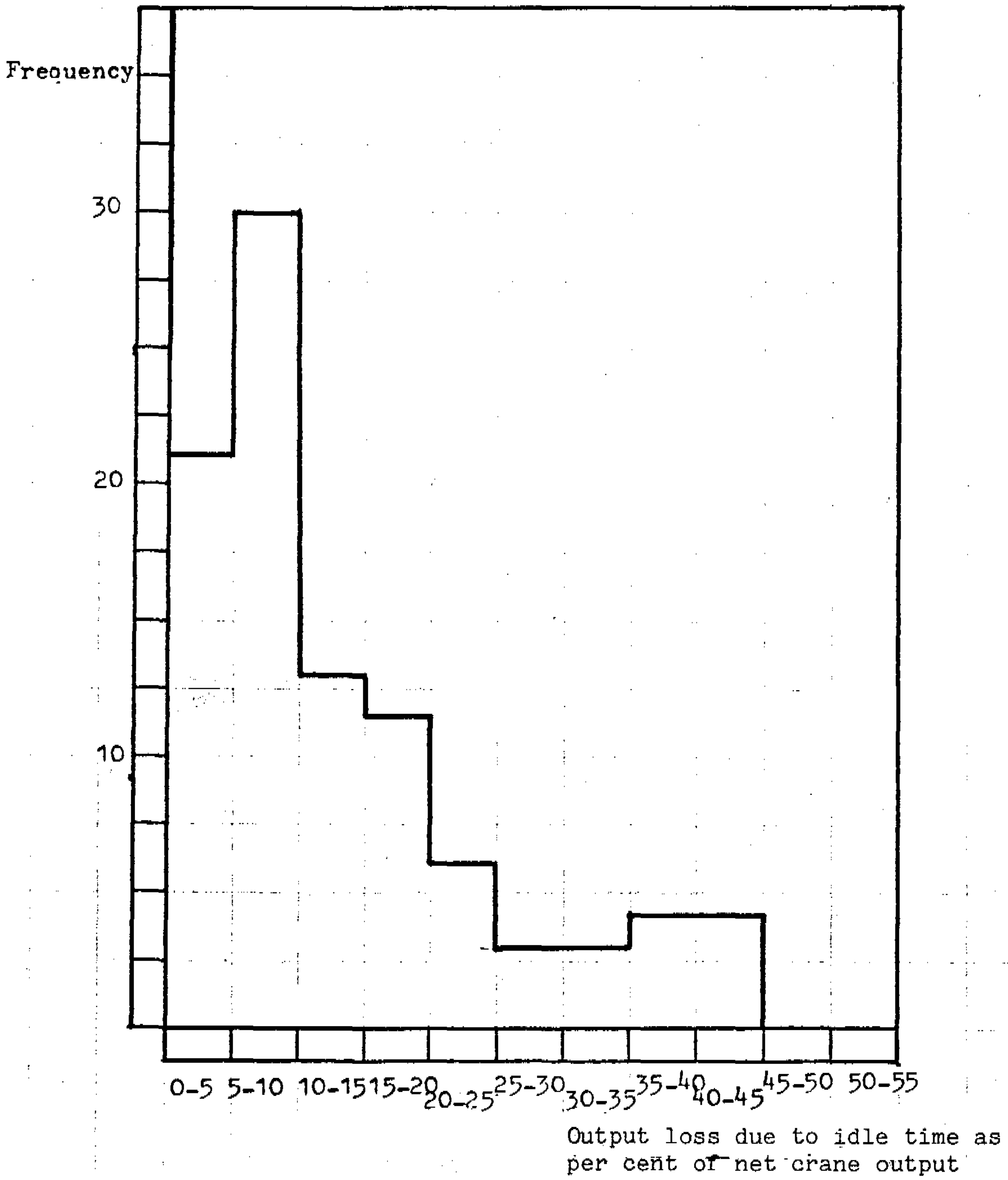
Container terminal performance returns based on information published by IAPH (April-June 1978)

	Number of containers	Number of ships	Average number of containers handled per ship	Average output rate when working (per hour per ship)	Output per 24 hours
25 ports in sample	866 866	3 244	267	14.2	353

40. Figure 20 presents graphically the importance of idle time incurred during the shift when gangs were allocated but work was interrupted. In conventional operations total idle times can be substantial and effectively annul the results of high net gang productivity. 15/ The average of 13 per cent loss in output due to idle time (measured as a per cent of net crane output) is a low figure and confirms the lesser vulnerability of container operations. Nevertheless some avoidable causes remain predominant at certain terminals. These include stoppages due to damaged containers, lack of operational information, equipment breakdown and arrival delays (for ships or export containers). Apart from a few terminals the difference between net and gross crane productivity lies within the 0-20 per cent range.

Figure 20

Loss of output due to idle time



Size of sample: 93

Mean: 13.3 per cent

Source: Calculated on the basis of data provided by leading container consortia.

41. The average number of cranes used also varies significantly from terminal to terminal, as illustrated in figure 21. From the absolute minimum of one gantry crane, the allocation pattern goes to a mean of 1.76, with a median of 1.8 and a maximum allocation of 2.8 cranes per ship. These values represent three-month averages for second- and third-generation ships. From the detailed information available it is clear that crane allocation is very much tied to the ship's size, the number and distribution of the containers over the various bays, and the ports' gantry crane potential (compared to the total requested number of cranes for a specified work-period). Thus, further short-term improvements are unlikely to be achievable once a certain pattern is set. Only long-term terminal planning along with improved distribution over the ship's bays could permit the allocation of a higher gantry crane quota per ship. Effectively then, the potential improvement from an increased number of gantry cranes per ship is relatively limited and restricted to those terminals which are operating with less than an average of 2.0 cranes. This is all the more true as terminal operators have observed a relative decline in crane output which UNCTAD's study on port development 16/ puts as follows:

One crane on one berth - output factor 1.0;

Two cranes on one berth - output factor 1.8;

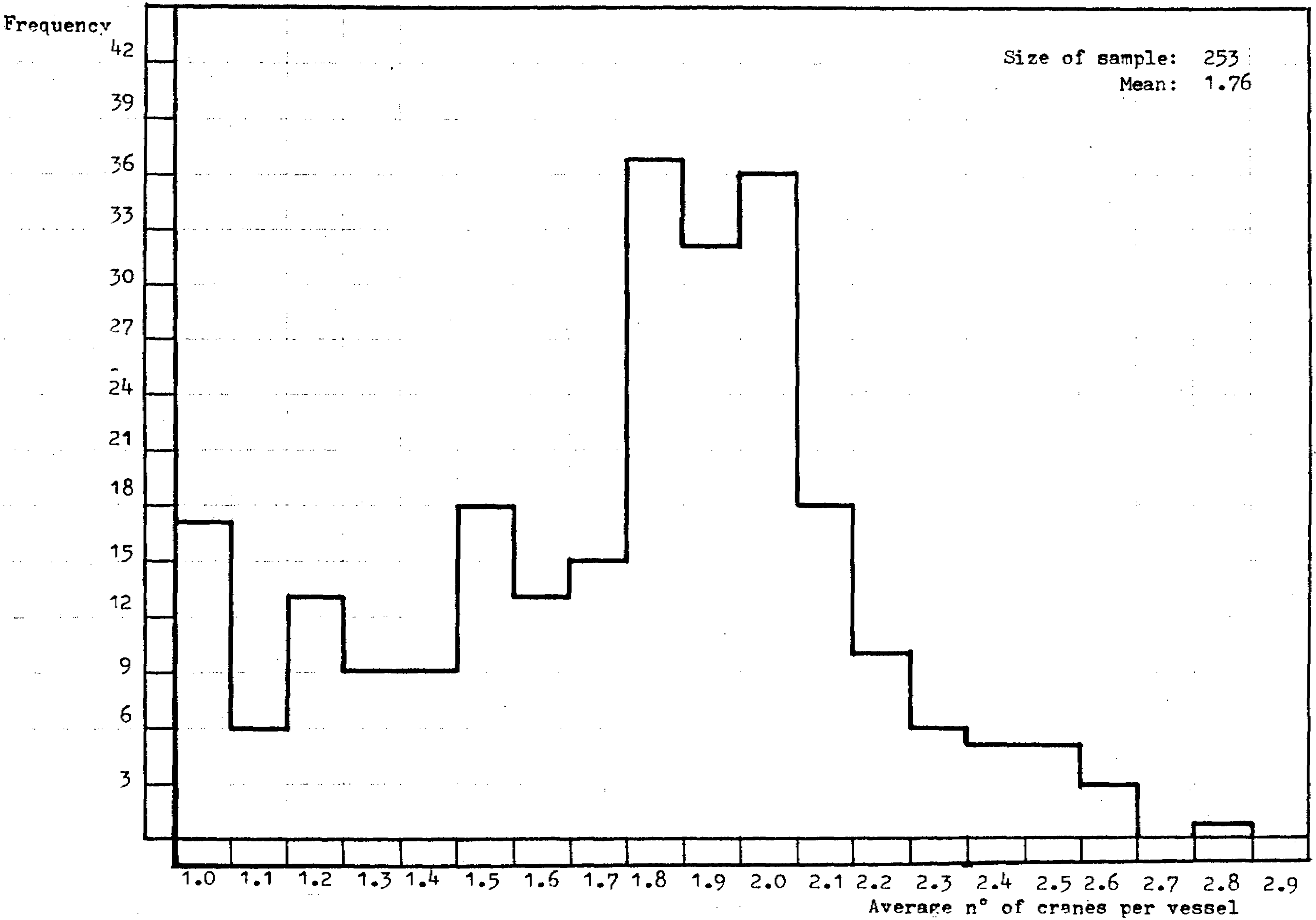
Three cranes on two berths - output factor 2.4.

42. All the above-mentioned output information is based on a very large sample of 7.5 million container exchanges on second- and third-generation ships. The IAPH data, which covered all ship types in the responding ports, show equally dramatic differences between terminals but at a lower overall level, as shown in tables 13 (a) and 13 (b). The striking feature remains the persistent strong variations in output rates per hour and on a 24-hour basis. 17/ This is especially remarkable given that a container terminal is the "typical" example of a standardized and mechanized operation, which, in theory at least, should lead to equalized output rates. However, many factors continue to influence a container terminal's performance and lead to strongly differentiated output rates. The more significant of these influences are as follows:

- Balance (or lack of balance) between the various subsystems at a terminal;
- Motivation and quality of container terminal personnel;
- Size and type of vessel;
- Total number of container exchanges per call;
- Place of terminal in "port of call" sequence;
- Number, type and capacity of cranes employed on a vessel;
- Stowage distribution pattern over the bays of the vessel;
- Stowage position in the bays (under deck/on deck);

Figure 21

Average crane allocation pattern



- Number of outsized containers (or other units);
- Lashing systems utilized for on-deck containers;
- Proportion of import/export/trans-shipment/transit containers;
- One-way or two-way handling;
- Multi-user or limited-user facility;
- Allocation of handling equipment on terminal.

43. In comparison with conventional operations, factors such as weather conditions and type of shift play a lesser role, whilst modal split, packing and consignment sizes are no longer of much validity. The single most important factor, however, remains the existence or lack of balance between the various subsystems on a terminal. Unfortunately this is an awkward and very difficult element to quantify accurately, as it calls for an in-depth investigation of such intangibles as the terminal's structure and its instruction/information lines of communication between different system parts and control units.

44. A supplementary analysis further illustrates the incredible fluctuations that are observed in container terminal output rates. On a single terminal the three-monthly output averages were compared for two distinct services. The results reproduced in table 14 defy any logical explanation based on seasonal influences, more difficult operating conditions due to congested conditions at the terminal, or overall improvement of operating standards. Indeed the fluctuations are not only irregular over time but are also contradictory for the same time period between the two services. Moreover it may be appropriate to underline that the terminal on which table 14 is based is not an exception and that the same observations can be made for other terminals listed in tables 8 through 11.

45. Measuring cargo-handling productivity on roll-on/roll-off ships involves the additional difficulty that although the type of ro/ro ship is of decisive importance, it cannot easily be defined or classified. In respect to productivity three interrelated classifications should be considered, namely one by service type (short-sea, deep-sea), one by cargo type (road trucks/rail waggons, cargo on bolsters, loose cargo, cargo on ro/ro trailers, containers, other unit loads) and one by ramp type (straight bow or stern ramp; quarter-angled or slewing ramp; side-ramp(s) in conjunction with other bow or stern ramps). One could further add an extra classification by internal hoist or transfer arrangements (ramps or elevators), but by and large the scarce available productivity data on ro/ro ships do not give much detail on the impact of any of these factors. 18/ The better quality information available covering a large sample of ports over a three-year period is presented in table 15.

Table 14

Comparison of output rates for two different services on same terminal
(Containers per 24 hours at berth)

A. Terminal A

Time period		Service 1 (second-generation ships)	Service 2 (third-generation ships)
1974	Jan. - Mar.	209	376
	Apr. - June	219	395
	July - Sept.	412	394
	Oct. - Dec.	547	539
1975	Jan. - Mar.	279	677
	Apr. - June	198	454
	July - Sept.	590	726
	Oct. - Dec.	562	679
1976	Jan. - Mar.	268	653
	Apr. - June	624	646
	July - Sept.	179	798
	Oct. - Dec.	279	691
1977	Jan. - Mar.	479	452
	Apr. - June	481	524
	July - Sept.	566	535
	Oct. - Dec.	299	651
1978	Jan. - Mar.	218	520
	Apr. - June	377	448
	July - Sept.	434	528
	Oct. - Dec.	401	380
1979	Jan. - Mar.	199	549
	Apr. - June	226	489
	July - Sept.	329	651
	Oct. - Dec.	323	501
1980	Jan. - Mar.	403	731
	Apr. - June	400	642
	July - Sept.	330	705
	Oct. - Dec.	400	695
1981	Jan. - Mar.	413	815
	Apr. - June	549	613

Table 14 (continued)

B. Terminal B

Time period		Service 1 (second-generation ships)	Service 2 (third-generation ships)
1974	Jan. - Mar.	346	398
	Apr. - June	569	587
	July - Sept.	735	553
	Oct. - Dec.	624	450
1975	Jan. - Mar.	540	649
	Apr. - June	239	754
	July - Sept.	315	425
	Oct. - Dec.	384	397
1976	Jan. - Mar.	616	497
	Apr. - June	636	563
	July - Sept.	733	731
	Oct. - Dec.	452	517
1977	Jan. - Mar.	405	469
	Apr. - June	628	545
	July - Sept.	681	463
	Oct. - Dec.	512	560
1978	Jan. - Mar.	570	457
	Apr. - June	485	464
	July - Sept.	381	580
	Oct. - Dec.	369	495
1979	Jan. - Mar.	289	454
	Apr. - June	363	544
	July - Sept.	400	602
	Oct. - Dec.	340	481
1980	Jan. - Mar.	514	599
	Apr. - June	303	515
	July - Sept.	504	537
	Oct. - Dec.	452	566
1981	Jan. - Mar.	455	732
	Apr. - June	328	718

Source: Data supplied by a number of shipping lines.

Table 15

Output on roll-on/roll-off ships

Port	Hours in port			Average weight tonnes per hour in port		
	1980	1981	1982	1980	1981	1982
a	15	16	27	138	154	157
b	78	38	38	89	73	86
c	77	71	65	68	80	94
d	78	58	56	124	150	176
e	32	35	36	32	45	51
f	20	19	19	108	119	138
g	46	55	56	139	95	129
h	24	23	27	95	99	69
i	80	55	81	63	97	69
j	37	42	43	87	75	59
k	43	69	70	85	54	54
l	21	17	15	162	127	116
m	12	13	12	198	195	215
n	10	9	7	166	131	46
o	8	9	13	198	141	122
p	17	15	11	45	72	75

Source: Data supplied by a number of shipping lines.

46. Another, more general indication of achievable productivity in a roll-on/roll-off operation distinguishes between the size of the vessel on the one hand and the type of rolling cargo that is being handled on the other. Table 16 gives an example of this.

Table 16

Roll-on/roll-off productivities by ship size and by type of rolling cargo handled
(Units per hour)

Ship size	Type of rolling cargo		
	Trailers	Mafi trailers	Cars
Less than 5,000 dwt tonnes	15	10	100
Between 5,000 and 10,000 dwt tonnes	20	15	175
Above 10,000 dwt tonnes	25	20	250

Source: Data supplied by a number of shipping lines.

47. In conclusion then, one can state that for roll-on/roll-off operations the figures quoted above also fall well below the values given by roll-on/roll-off proponents. This is understandable as such values are "public relations" oriented, and accuracy is not the most important consideration by far. However, given the daily cost of a deep-sea-going roll-on/roll-off ship, the ratio of ship's cost at berth to tonnage handled is strikingly unsatisfactory. 19/ Finally, very wide variations of the output figures around the mean are also very prevalent in the case of roll-on/roll-off ships. The combination of the many factors mentioned for general cargo in paragraph 31 and the major underlying factors listed for container handling in paragraph 42 explain to a large extent the observed differences. Moreover, the more restricted access in a roll-on/roll-off ship and the need to take account of very strict discharging/loading sequences further help to elucidate these variations from terminal to terminal, which are a function of:

(a) The actual position of a terminal in the sailing programme of a roll-on/roll-off line;

(b) The extreme differences in vessel type, vessel lay-out and ramp capability and capacity;

(c) The heterogeneous character of cargo mixes from terminal to terminal.

4. Comparing port performance values

48. The preceding discussion of various output and productivity measures has established beyond any doubt that a port's or a terminal's performance cannot be assessed on the basis of one single figure. An accurate description of a port's (or terminal's) behaviour in relation to the demand placed on it can only be obtained from the continuous monitoring of a set of coherent indicators. The collection, analysis and presentation of the data calls for specialist inputs, and the conversion of the facts into policies should be one of top management's priority tasks. Unfortunately, in many world ports, there still remains a tendency to amass an uncontrollable amount of raw data, which is subsequently processed in an impressive but generally impractical statistical book. Hence the information thus available is rarely used in an effective way (i.e. for short-term, medium-term or long-term planning, for monitoring daily operations, for adjusting intrinsic weaknesses in one of the port's subsystems, etc.).

49. Probably even more disturbing is the fact that whoever makes the effort to study the statistical material thus collected will discover that much of it is of rather limited use, whilst vital information (waiting and service times, output and productivity expressed as a function of time and cost) is often lacking, incomplete or superseded. The limited value of the available statistical information automatically reduces its scope of application, but the effort put into the data collection and analysis still amounts to many man-hours of specialist time. Hence the cost of the exercise is perceived as being far too high. In times of austerity, the decision to discontinue an expense which is not considered of direct benefit is therefore almost automatically imposed. Even in those ports where the quality of the data and their usefulness are beyond discussion, the indirect or long-term benefits of the availability of reliable data make it difficult for a port management to

justify the expenses involved. The same argument holds for large-scale productivity research projects. After a short time the firms participating in, and obviously paying for, the study become dissatisfied with the short-term results, which in themselves cannot solve the management and operating difficulties which led to the commissioning of the study. This disenchantment quickly leads to the discontinuation of the data sampling and analysis, and thus the lack of adequate and representative data persists. The above-mentioned reactions do not stop all sensible data collection. A minimum data set will be provided by most ports on a standard basis, but generally with long delays. Some of this data is related to output, throughput and occasionally also productivity. It is mostly used for public relations and publicity, and very rarely for the improvement or streamlining of operations or management.

50. The use of performance indicators by the respective port authorities or terminal operators often leads to abusive comparisons and misleading conclusions. In most cases output figures are simply enumerated, without providing the necessary detail as to the conditions under which these results were obtained. Port authorities, when publishing throughput figures, fail to distinguish between port traffic and cumulative berth throughput figures. Worse still, they compare dissimilar situations (e.g. consignment sizes, tonnages handled per call, cargo mixes, packaging and port facilities may all be very different). As a general rule, one should be extremely cautious when comparing output or throughput values, even between ports in the same range, between terminals in the same port and between different shipping lines at the same terminal. Comparisons are obviously useful, and up to a point indispensable. Terminal operators for example feel the need to evaluate their performance with respect to performance in neighbouring or in overseas ports. The danger of such a practice does not lie in the comparison itself, but rather in the absence of any similarity between the operations thus equated, as well as the lack of any substantiating factor which would bring out the vital differences. Thus, for example, stating that terminal A achieved 2,500 tonnes per 24 hours loading structural steel of 12 metre lengths and terminal B only 1,500 tonnes clearly marks the latter port as far less efficient than the former. However, if further evidence were provided, such as the fact that terminal A loaded in 50,000 dwt bulk carriers with large hatch openings and terminal B in conventional 15,000 dwt vessels, and that the average B/L size for A was 20 tonnes and for B just about 1 tonne, then the superior output of A could justifiably be questioned. Given the large number of parameters, the purist cannot easily accept the value of port performance comparisons. He will consider them inaccurate, insignificant or not very relevant. Nevertheless, it is difficult to stop ports from perpetuating such practices, and thus the chances are slim that port managers will suddenly refrain from making unsound or unfounded comparisons. At best it may be possible to enhance, through better training of port staff, the understanding of port performance measures and their underlying complexities. At worst the traditional practices will be continued, thus limiting the real significance of the data presented.

51. The essential question remains how far the performance achieved in respect of a given parameter can be improved and whether such improvement is desirable or not from the point of view of overall performance. A substantial reply can only be given in full knowledge of the port's or terminal's objectives (i.e. the relative priority of the various operational and

financial goals). To illustrate the points raised, it is assumed that one major priority objective will be retained: the achievement of the highest possible productivity value given the present operating context (and expressed in tonnes per monetary unit input - thus dollars per tonne). According to the law of diminishing returns, a cut-off output figure can be determined at which the highest productivity level, in a given operational framework, is obtained. An example will help to clarify this point.

52. Using the case of the relative decline in crane output rates, the following situation may occur:

	Average crane output (moves/hour)	Annual capital cost	Annual operating and maintenance cost (based on 2,000 operating hours)	Total annual cost	Cost per move (based on 2,000 operating hours per year)
Gantry crane type 1 $3,000,000 1/	20	390 000	100 000	490 000	$12.25
Gantry crane type 2 $5,000,000 1/	30	650 000	165 000	815 000	$13.60

1/ It is assumed that both crane types can handle first-, second- and third-generation container ships.

Based on cost per move, the gantry crane of the first type is obviously the best choice for the terminal operator, but in a real-life situation other factors may be more decisive in the final choice. These may include the cost of the ship's time in port (depending on the length of the intervals the vessel spends in the port away from the berth, this factor may be particularly crucial), the terminal's "image" to the shipping industry, the available resources at the time the investment is decided, etc.

53. The above principle, which refers to a specific equipment item in a container terminal, is found in virtually all port handling situations, the most classical example being that of gang allocation in a conventional or neo-bulk operation, where different allocation patterns can strongly influence expected productivity.

54. A final point deserves special emphasis. The comparison of output figures over a prolonged time period, and under comparable conditions, leads to the significant but not surprising conclusion that all major improvements have been the result of an increase of the unit set weight handled. The formulas for calculating the intrinsic capacity of the ship-to-shore, transfer, stacking and delivery subsystems each contain the unit set weight as major parameter. Thus:

Intrinsic capacity of ship-to-shore subsystem = Average unit weight per set x No. of cycles intrinsically achievable.

For example, in the case of bagged cargo (60 kg bags) and conventional cranes of 3 to 6 tonnes:

Intrinsic capacity of ship-to-shore subsystem = 1.2 tonnes x 20 cycles/hour

= 24 tonnes/hour.

55. In fact, all basic cargo-handling improvements have primarily endeavoured to further augment the unit set weight, hence the trend towards more gigantic unit-loads, from pallets to pre-slung units, to bundled timber, to bales of woodpulp, to heavy coils and of course to the ubiquitous container. Hence also the move towards larger and larger grabs for handling certain bulk cargoes. Thus the intrinsic capacity of the ship-to-shore subsystem has grown, not by 10 or 20 per cent (the likely maximum gains from increasing crane cycle speeds 20/), but by a factor of 5, 10 or 20. A notable part of the so-called technological revolution in shipping and ports has originated and is still developing around this increase of unit-weights and their improved handling capability.

56. The only other condition that has to be fulfilled before intrinsic capacity can be equated with actual capacity is in fact the prevention of imbalances between the subsequent subsystems. However, the latter is a task often more formidable than the purchase of sophisticated handling equipment, and one for which only an in-depth knowledge of the interrelationships between the component parts of berths (or terminals), and a solid understanding of the determinant productivity parameters, can produce a satisfactory solution.

Notes

1/ United Nations publication, Sales No. E.74/II.D.1.

2/ For a break-bulk berth group the assumption is random arrivals and an Erlang 2 service distribution ($M/E_2/n$). For specialized terminals the assumption used is that the intervals between arrivals are best described by an Erlang 2 distribution (thus E_2/E_2n is the queueing theory notation).

3/ Namely the flexibility that exists in a port system and actually allows port management to introduce certain contingency measures, which reduce considerably the expected waiting times (as mathematically forecast).

4/ See also the more detailed discussion on output and productivity, in which the importance of these factors is discussed more extensively.

5/ The higher output per ship-hour provides an inherent saving in ship's time in port, at least on condition that non-operational periods at berth or in the port are not unduly lengthened through waste or constraints (e.g. the vessel may be ready to sail earlier, but a shortage of pilots could well annihilate this gain and keep the ship in port as long as before). In the above example, for a ship with a daily cost of $4,800 and 1,000 tonnes of cargo, the potential saving in shiptime (11.7 hours) could reduce the total overall cost by over $1,000.

6/ Not infrequently labour costs are both: dockworker wages are a fixed cost for the part covering normal shift hours and a variable cost for the overtime supplements.

7/ In fact, it is mechanization that has largely contributed to the shift from casual labour (i.e. variable cost) to permanent staff (i.e. fixed cost).

8/ For example, it is still sometimes wrongly assumed that the optimum berth occupancy value is 100 per cent.

9/ See annex I for an example with a suggested form for recording berth utilization.

10/ See table 2 for the three-berth case.

11/ Berth throughput: Systematic methods for improving general cargo operations; British Ports Association, General Council of British Shipping, National Ports Council, Port Performance Comparison Study - General Cargo in Conventional Vessels (London, 1977); "Research into productivity", a study sponsored by Scheepvaartvereniging Nort and Scheepvaartvereniging Zuid, the Employers Associations of the Ports of Amsterdam and Rotterdam, and carried out by Raadgevend Bureau Berenschot (although the study was published in Dutch only, an English summary appears in a paper entitied "Managerial tools for improving productivity" delivered by H. J. Melessen at the ICHCA 9th International Conference on Handling International Cargo in Göteborg, 1969).

12/ See Berth throughput: Systematic methods for improving general cargo operations (United Nations publication, Sales No. E.74.II.D.1).

13/ Case study carried out in 1971-1972.

14/ Also, in a container terminal environment the "bottle-neck" theory remains acutely valid. Generally speaking, the ship-to-shore system has a marked overcapacity, whilst in particular horizontal transfer, stacking and storage systems suffer from inadequate means.

15/ Most cargo-handling companies distinguish between avoidable and non-avoidable idle times. The latter normally include weather conditions, non-port-related political strikes, acts of God, etc., the former the more common causes such as equipment breakdowns, waiting for ship, lorry or truck arrivals, late start and/or early finish, (un)lashing, opening and closing hatches, labour strife, etc.

16/ Port development: A handbook for planners in developing countries (United Nations publication, Sales No.E.84.II.D.1).

17/ This fact is also brought out in the productivity data published by H.K. Dally in his "Review of British Container Terminals", National Ports Council Bulletin, No.16, May 1981, pp.1-14.

18/ How difficult it may be to measure such productivities can be illustrated by the following example:

A roll-on/roll-off ship of 16,744 grt:

discharged:	96 empty 20' containers
	80 empty 20' bolsters
	1 empty 40' container
shifted:	1 empty 20' container
	7 full 20' bolsters
	2 full mafi's
	5 self-sustained units
loaded:	23 full 20' containers
	85 full 20' bolsters
	4 self-propelled vehicles
	17 cars

in four gang-shifts of eight hours each.

On what basis can one calculate the hourly output?

19/ If we assume that the second-generation roll-on/roll-off vessel costs $20,000 per day, and retaining an output of 100 tonnes per hour in port (by far not the worst productivity achieved according to table 15), then the ship's cost in port per tonne amounts to $8.3/tonne. In financial terms this must be an excessive burden to the shipping line, since it is a one-way cost only.

20/ A modest increase in crane cycle speeds which, however, demands considerable additional capital outlays.

Annex I

EXERCISE ON BERTH OCCUPANCY a/

The berth occupancy record of Zone A in a hypothetical port, Port Laedi (berths 7, 8, 9) for the first week of October provides the attached day-by-day information.

You are requested to calculate the berth occupancy for Zone A for the week 2-8 October and to present the result graphically, making a distinction between:

Berth not occupied;

Berth occupied - by non-operational vessels (or not workable);

Berth occupied - by operational vessels not working;

Berth occupied - by operational vessels working.

Available working shifts	DAY	08.00 - 16.00
	1st	06.00 - 14.00
	2nd	14.00 - 22.00
	NIGHT	22.00 - 06.00

No work on Sundays

Berth lengths are as follows:	No. 7:	165 m
	No. 8:	165 m
	No. 9:	170 m
	Total Zone A =	500 m

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a/ Taken from "Manual on a uniform system of port statistics and performance indicators" (UNCTAD/SHIP/185). This exercise will allow the reader to apply some of the principles described in this monograph.

DATE	BERTH 7	BERTH 8	BERTH 9
MONDAY 2/10	ARIANE (160 m) 06.00-14.00 (3 gangs) left berth 16.30	not occupied	TRAFIAKI (165 m) arrived 09.00 14.00-22.00 (4 gangs) 22.00-06.00 (4 gangs)
TUESDAY 3/10	not occupied	DESDEMONA (130 m) arrived 13.00 14.00-22.00 (2 gangs) left 23.00	TRAFIAKI (165 m) 06.00-14.00 (4 gangs) 14.00-20.00 (2 gangs) left 21.00
WEDNESDAY 4/10	SEA CHALLENGER (145 m) arrived 02.00 06.00-14.00 (2 gangs) 14.00-22.00 (2 gangs) MASTER CARRIER (135 m) abreast berthed arrived 11.00 14.00-22.00 (3 gangs) left abreast berth 24.00	EXPLORER (130 m) arrived 05.00 06.00-14.00 (2 gangs) 14.00-22.00 (3 gangs) 22.00-06.00 (2 gangs)	ORFEE (155 m) arrived 07.00 08.00-16.00 (2 gangs) 14.00-22.00 (2 gangs) 22.00-06.00 (3 gangs)
THURSDAY 5/10	SEA CHALLENGER (145 m) 06.00-14.00 (2 gangs) 14.00-18.00 (1 gang) left berth 19.00	EXPLORER (130 m) 06.00-14.00 (2 gangs) 08.00-16.00 (1 gang) 14.00-22.00 (2 gangs)	ORFEE (155 m) left berth 12.00 ZANZIBAR (80 m) arrived 14.00 15.00-22.00 (3 gangs)
FRIDAY 6/10	AMUNDSEN (175 m) arrived 02.00 06.00-14.00 (5 gangs) 14.00-22.00 (5 gangs) 22.00-06.00 (3 gangs) SEAWAY EXPRESS (130 m) abreast berthed arrived 05.00 06.00-14.00 (3 gangs) 14.00-22.00 (3 gangs) 22.00-06.00 (2 gangs)	EXPLORER (130 m) 08.00-16.00 (1 gang) left berth 19.00 ORINOCCO (160 m) passenger vessel arrived 23.30	ZANZIBAR (80 m) 06.00-14.00 (2 gangs) 14.00-17.00 (2 gangs) left berth 23.00 SUEZ (70 m) arrived 11.00 14.00-22.00 (1 gang)
SATURDAY 7/10	AMUNDSEN (175 m) 06.00-14.00 (3 gangs) 14.00-21.00 (2 gangs) SEAWAY EXPRESS (130 m) abreast berthed 06.00-14.00 (2 gangs) 14.00-21.00 (2 gangs) left abreast berth 23.00	ORINOCCO (160 m) passenger vessel	SUEZ (70 m) 06.00-12.00 (1 gang) left berth 14.00
SUNDAY 8/10	AMUNDSEN (175 m) left berth 10.00	ORINOCCO (160 m)	FREEDOM 11 (155 m) arrived berth 17.00

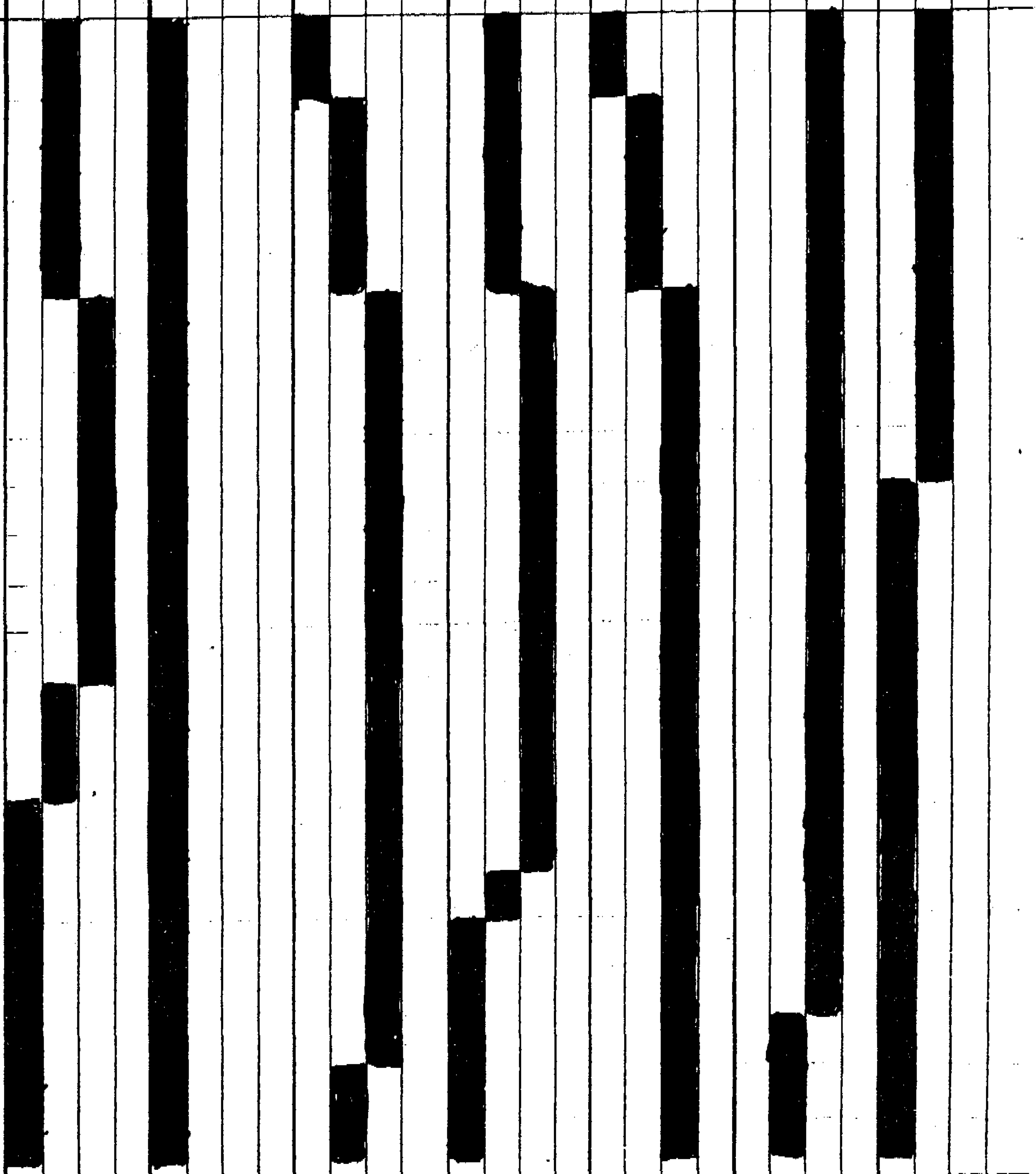
PORT: LAEDI

ZONE: A

BERTH: 7

WEEKLY REGISTER OF BERTH OCCUPATION

DATE FROM: 02/10 TO: 08/10



HOURS	MONDAY				TUESDAY				WEDNESDAY				THURSDAY				FRIDAY				SATURDAY				SUNDAY			
	1*	2*	3*	4*	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
01																												
02																												
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TOTAL	7½	8½	8	–	24	–	–	–	2	6	16	–	5	7	12	–	2	4	18	–	–	3	21	–	14	10	–	–

*CODE: 1 - vacant; 2 - occupied not working; 3 - occupied working;
4 - occupied not workable

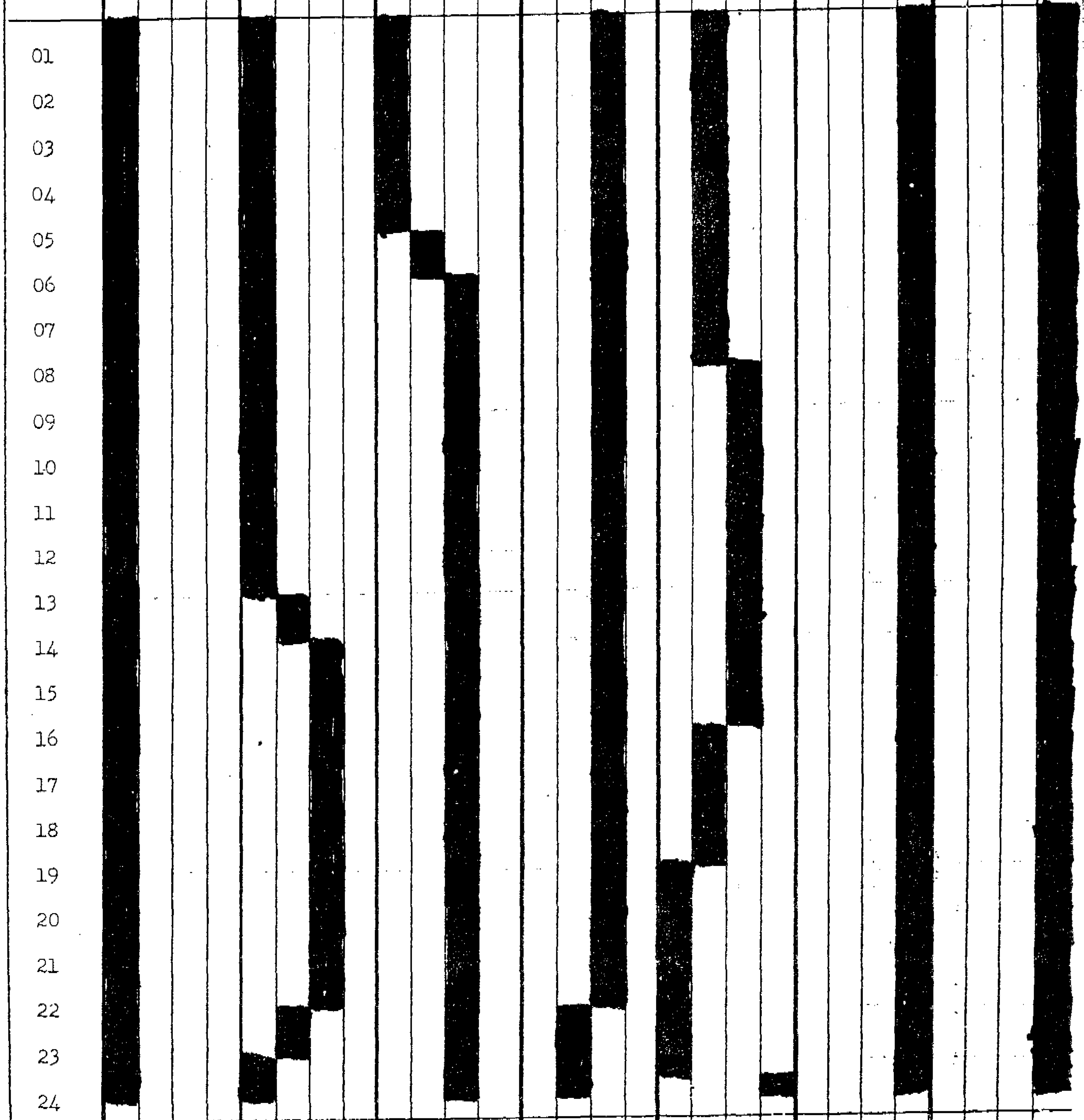
PORT: LAEDI

WEEKLY REGISTER OF BERTH OCCUPATION

ZONE: A

DATE FROM: 02/10 TO: 08/10

BERTH: 8



HOURS	MONDAY				TUESDAY				WEDNESDAY				THURSDAY				FRIDAY				SATURDAY				SUNDAY			
	1*	2*	3*	4*	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
TOTAL	24	-	-	-	14	2	8	-	5	1	18	-	-	2	22	-	4½	11	8	½	-	-	-	24	-	-	-	2

*CODE: 1 - vacant; 2 - occupied not working; 3 - occupied working;
4 - occupied not workable

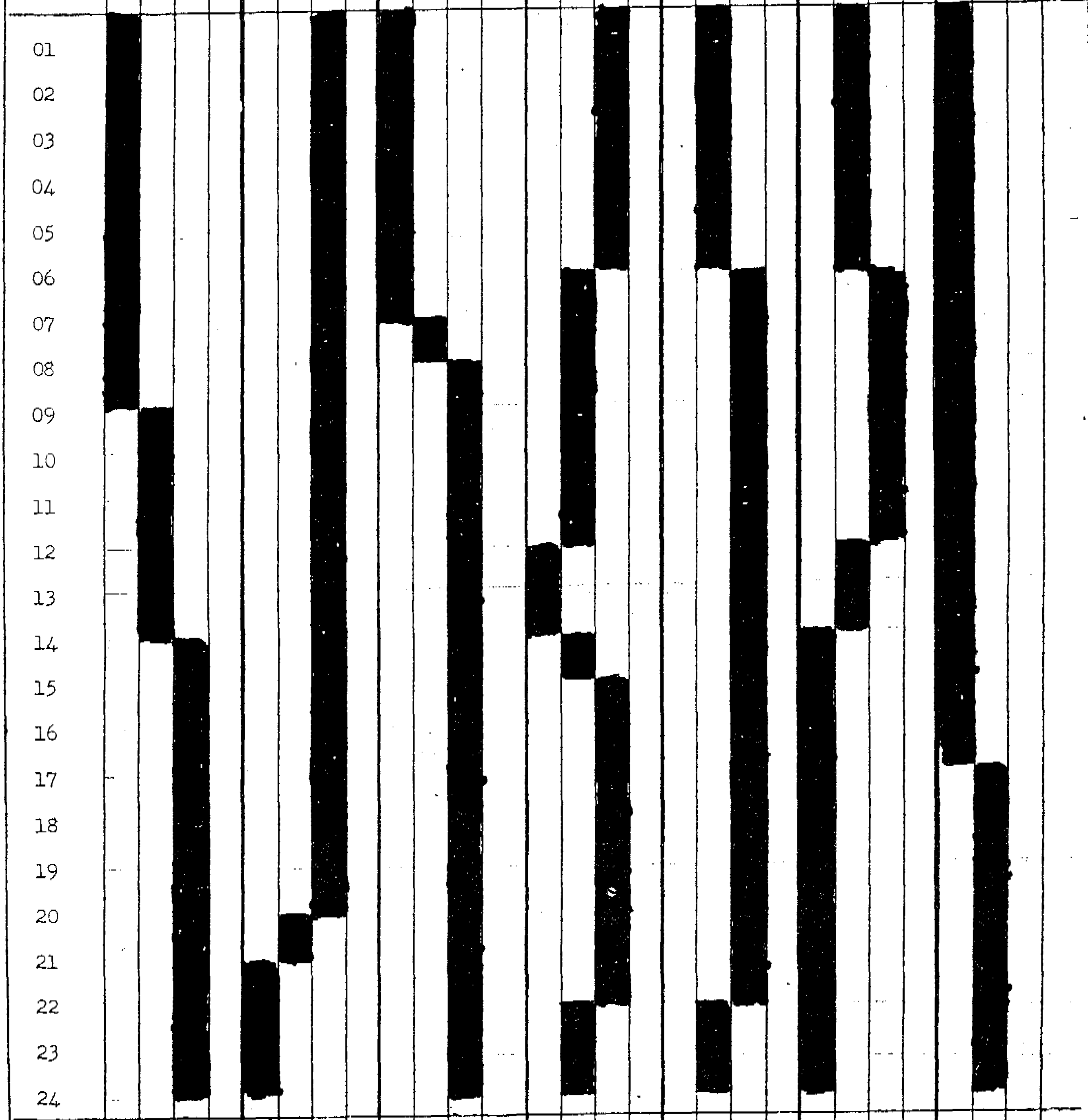
PORT: LAEDI

ZONE: A

BERTH: 9

WEEKLY REGISTER OF BERTH OCCUPATION

DATE FROM: 02/10 TO: 08/10



HOURS	MONDAY				TUESDAY				WEDNESDAY				THURSDAY				FRIDAY				SATURDAY				SUNDAY			
	1*	2*	3*	4*	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
TOTAL	9	5	10	–	3	1	20	-	7	1	16	–	2	9	13	–	–	8	16	–	10	8	6	–	17	7	–	–

*CODE: 1 - vacant; 2 - occupied not working; 3 - occupied working;
4 - occupied not workable

PORT: PORT LAEDI

BERTH OCCUPANCY FORM

SHEET 1/2

ZONE: A

MONTH: OCTOBER

DATE FROM: 02/10 TO: 08/10

DATE	BERTH No.	TIME				
		VACANT	OCCUPIED NOT WORKING	OCCUPIED WORKING	OCCUPIED NOT WORKABLE	CHECK TOTAL
02/10	7	7.5	6.0 2.5	8.0		24.0
	8	24.0				24.0
	9	9.0	5.0	8.0 2.0		24.0
03/10	7	24.0				
	8	13.0 1.0	1.0 1.0	8.0		24.0
	9	3.0	1.0	6.0 8.0 6.0		24.0
04/10	7	2.0	4.0 2.0	8.0 8.0		24.0
	8	5.0	1.0	8.0 8.0 2.0		24.0
	9	7.0	1.0	6.0 8.0 2.0		24.0
05/10	7	5.0	6.0 1.0	8.0 4.0		24.0
	8		2.0	6.0 8.0 8.0		24.0
	9	2.0	6.0 1.0 2.0	6.0 7.0		24.0
06/10	7	2.0	4.0	8.0 8.0 2.0		24.0
	8	4.5	8.0 3.0	8.0	0.5	24.0
	9		6.0 2.0	8.0 3.0 5.0		24.0
SUB-TOTAL		109.0	65.5	185	0.5	360.0
PERCENTAGE						

PORT: PORT LAEDI

BERTH OCCUPANCY FORM

SHEET 2/2

ZONE: A

MONTH: OCTOBER

DATE FROM: 02/10 TO: 08/10

DATE	BERTH No.	TIME				
		VACANT	OCCUPIED NOT WORKING	OCCUPIED WORKING	OCCUPIED NOT WORKABLE	CHECK TOTAL
07/10	7		3.0	6.0 8.0 7.0		24.0
	8				24.0	24.0
	9	10.0	6.0 2.0	6.0		24.0
08/10	7	14.0	10.0			24.0
	8				24.0	24.0
	9	17.0	7.0			24.0
TOTAL		150.0	93.5	212.0	48.5	504
PERCENTAGE		29.8	18.5	42.1	9.6	100

Total occupied: 70.2%

Annex II

SELECTED OUTPUT RATES IN THE PORT OF ANTWERP

Output rates in the port of Antwerp: general cargo break-bulk in modern liner vessels
(tonnes/gang/shift)

Terminal	Output
A	250 a/
B	250 b/
C	250
D	265
E	300
F	250
G	200

a/ Neo-bulk 375 tonnes/gang/shift.

b/ Cartons/bales/crates 250 tonnes/gang/shift.
Bags 400 tonnes/gang/shift.
Pallets 300 tonnes/gang/shift.

Output rates in the port of Antwerp: steel products
(tonnes/gang/shift)

	Terminals			
	B	C	D	E
Structural Steel < 12 m	600	450	540	600
Structural Steel > 12 m	600	400	330	450
Wire rods in bundles of 2t	750	500	5	900
Plate steel in packages of 2.5t	750	650	560	750
Steel tubes 12 m-2 tonnes	700	450	400	450
Coils up to 5 tonnes	1 200	950	730	1 100
5 to 10 tonnes	1 400	1 200	990	1 600
above 10 tonnes	1 600	1 500	1 120	2 000

Output rates in the port of Antwerp: container handling
(Containers/hour)

	Gantry crane	Mobile crane
Fully cellular ships	A 35	
	B 25	B 25
	C 30	C 22
		D 17-22
	F 20	
	G 27	G 23
Semi-container ships	A 20	
	B 23	B 23
	C 18	C 15
	F 20	
	G 22	G 20
Bulk-carrier	B 20-23	B 20-23
	C 18	C 15
	F 20	
	G 22	G 20
Forest products carrier	B 20-23	B 20-23
	C 22	C 27
	G 23	G 23

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