Maritime Economics & Logistics, 2005, 7, (1–18)

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A Mixed Integer Programming Model on the Location of a Hub Port in the East Coast of South America

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The paper introduces a mixed integer programming model on the selection of a hub port in the East Coast of South America, among a set of 11 ports that are servicing the regional demand for container transportation. Ports in Brazil, Argentina and Uruguay are considered, together with several origin/destination ports in the world. The model minimises total system costs, taking into account both port costs (dues and terminal handling charges) and shipping costs (feedering and mainline). In total, the model consists of 3,883 decision variables and 4,225 constraints. It turns up the port of Santos (Brazil) as the optimal single-hub solution, with the port of Buenos Aires (Argentina) as a close runner up. In addition, the model provides tentative estimates of improvements in demand and costs necessary to bring a certain port up to hub status. Despite some bold assumptions and limitations – mainly due to data availability – the model offers a straightforward decision tool to all ports in the world aspiring to achieve hub status and all that comes with it.
Maritime Economics & Logistics (2005) **7,** 1–18.
doi:10.1057/palgrave.mel.9100121

Keywords: Hub port; feeder services; container shipping; p-hub median problem; MILP.

INTRODUCTION

The competitive nature of liner shipping and the need to cut costs through economies of scale have led to a form organisation of container transportation known as the *hub-and-spoke* system. The size and capital intensity of modern containerships obliges them to limit their ports of call at each end to a minimum of 'hub' ports or 'load centres' such as Singapore, Hong Kong and Rotterdam, from where huge surges of containers are further forwarded (feedered) with smaller vessels to regional and local ports. Complex networks have thus developed whose fine-tuning and optimisation bears directly on trade and on consume welfare (Haralambides and Veenstra, 2000; Robinson, 1998; Zachcial, 1993). Schematically, such a (simplified) network can be seen in Figure 1.

MODELLING

According to Campbell (1994), hubs are facilities that serve as transhipment or switching points (eg in telecommunications), functioning as connection centres among several origins and destinations. A non-negative flow is associated to each origin–destination pair, together with its respective analysis attribute like, for instance, distance, time, or cost associated to the movement.

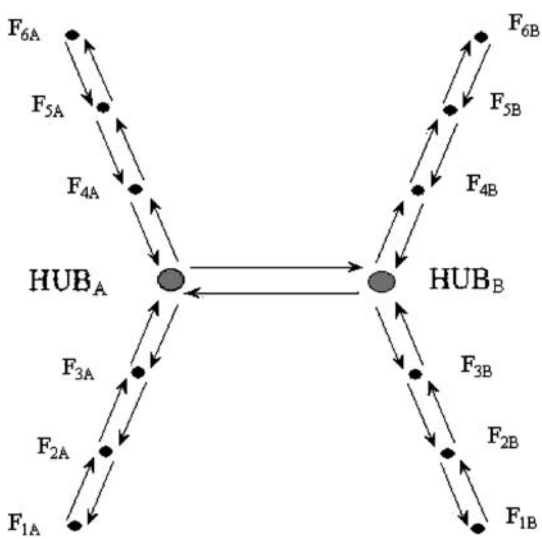

Figure 1: A hub-and-spoke network

Campbell (1994) discusses five types of discrete problems regarding the location of a hub:

- *P-hub median problem (P-HM)*
- *Uncapacitated hub location problem (UHLP)*
- *Capacitated hub location problem (CHLP)*
- *P-hub center problem (P-HC)*
- *Hub covering problem (HCV)*

It is worth mentioning that, in all five models, every direct movement from one origin to one destination is possible; or, in other words, every origin-destination movement is necessarily achieved by at least one hub.

The advantage of the Campbell formulations, in the context of classical transhipment models, is that they permit the tracking of containers by network; that is, origin and route for each final destination.

The UHLP differs from the P-HM in only two aspects: it does not define the number of hubs; it considers the total cost of the hub facility. The CHLP is an UHLP variation to which the capacity restriction of each hub is added. The objective of P-HC is to minimise *time* between origin-destination. HCV requires that the allocated hub covers an origin-destination pair only if the cost does not exceed a specified amount.

Table 1 shows the applicability of model classes. P-HM, UHLP and CHLP are applicable to terminal location problems, while P-HC and HCV are applicable to location problems of emergency service facilities (eg fire fighting department, police station) or vehicle location problems (eg ambulances).

Table 1: Model applicability

Model	Application
P-HM P-HM-TS UHLP UHLP-T CHLP	Location of transhipment terminal Focus: transportation and transhipment costs
P-HC1 P-HC2 P-HC1-T HCV HCV-P HMCV HMCV-T	Location of emergency service facilities or vehicles base Focus: service time

Table 2: Model characteristics

Model	Number of hubs	Hub fixed cost	Fixed cost of feeder line	Minimum flow of feeder line
P-HM	X			
P-HM-TS	X		X	X
UHLP		X		
UHLP-T		X		X
CHLP		X		
P-HC1	X			
P-HC2	X			
P-HC1-T	X			X
HCV		X		
HCV-P		X		
HMCV	X	X		
HMCV-T	X			X

Table 2 presents a summary of the main considerations in the above models, thus indicating at the same time their main differences. In general, the parameters of the 'fixed cost of feeder line' and the 'minimum flow of feeder line' cannot be easily quantified as they depend on operational (vessel dimensions) and market characteristics, respectively.

The P-HM model has been chosen from Campbell (1994). The model has been used earlier by O'Kelly (1986, 1987); Klincewicz (1991); and Aykin (1990). The original P-HM problem derives form the p-median problem, which was first presented by Hakimi (1964, 1965).

APPROACH TO THE PROBLEM OF HUB PORT LOCATION

According to Zan (1999), there are three 'stakeholders' to be taken into account in container shipping: port administration; carriers (ocean liner companies) and domestic shippers.

Zan's considerations can be depicted in Figure 2 where several interactions among the stakeholders can be observed. Therefore, model development must draw up the objective function from the perspective of a decision agent, that is, port, carrier or shipper.

However, as Figure 2 also shows, operational decisions, that is, route and frequency, are made by the carrier who, based on his shipping costs, port charges and demand from an origin port to a destination port, tries to maximise his income.

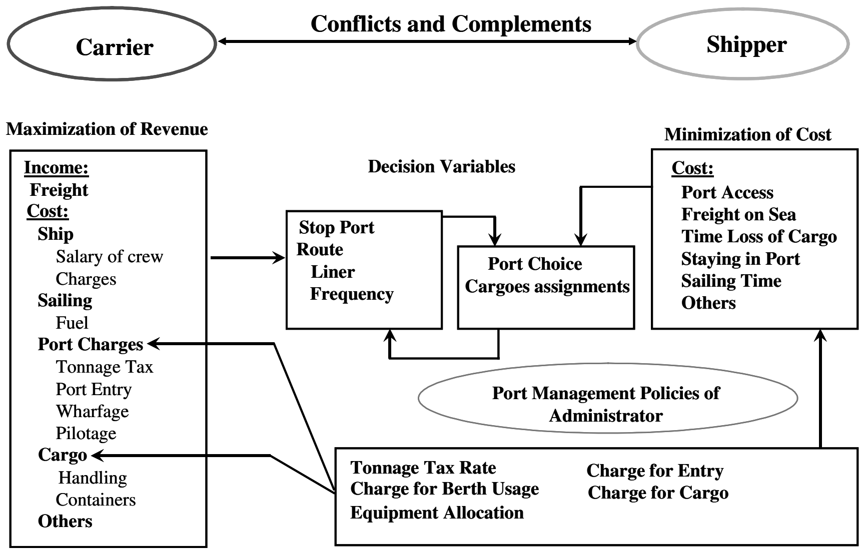

Figure 2: Relationships between port administration, carrier and shipper
Source: Zan (1999)

DEFINITION OF THE LOCATION MODEL

As mentioned above, the present model is based on the P-HM model by Campbell (1994). It attempts to provide better insights into hub-and-spoke (ie system) costs, as well as to study separately the import and export flows among feeder and destination ports, *via* one or more hub ports in the east coast of South America.

To limit the scope of analysis and the data requirements, which are heavy enough as it is, foreign origins/destinations have been aggregated in four world regions (see below).

Another aspect that had to be addressed is the differentiation of shipping and port costs between full or empty containers, and between 20 (TEU) and 40 (FEU) feet units. It is assumed that the unit cost of a maritime movement of one FEU is twice as high as this of one TEU, as the former occupies two slots on the vessel. On the other hand, port costs, in general, are moderately differentiated by container size, but *are* differentiated by container status; that is, full or empty. The following conventions have been used to denote the four types of containers: FCL_20: full TEU; EMP_20: empty TEU; FCL_40: full FEU; EMP_40: empty FEU.

The following section defines the model, from a carrier's perspective, laying out the parameters; constraints; decision variables; and objective function.

Indices:

f: indicates the feeder ports in the East Coast of South America, with $f = 1, 2, \ldots, F$;
m: indicates the area in the world that aggregates certain destination ports, with $m = 1, 2, \ldots, M$;
k: indicates the candidates to hub port status, with $k = 1, 2, \ldots, K$;
c: type of container (as described above), with $c = 1, 2, 3$ and 4;
s: container flow direction (import or export), with $s = 1$ or 2.

Parameters:

N: number of hub ports that must be allocated;
W_{fmcs}: import or export(s) of an f feeder port, to an m destination, of a type c container;
Δ_f: multiplication factor allowing for a W_{fmcs} flow variation of an f feeder port;
Q_{fmcs}: is the W_{fmcs} multiplication factor taking into account only the integer parcel, as can be seen in the following equation:

$$Q_{fmcs} = \text{int}(\Delta_f * W_{fmcs}) \tag{1}$$

$\beta\_C\_F_f$: parameter that allows changing terminal handling charges (THC) at port f;
$CP\_C\_F_{fc}$: THC per unit of type c container at port f;
$\beta\_N\_F_f$: parameter that allows changing port dues per unit of type c container at port f;
$CP\_N\_F_{fc}$: port dues per unit of type c container at port f;
CP_F_{fc}: port costs of f per unit of type c container as defined in the equation below:

$$CP\_F_{fc} = \beta\_C\_F_f * CP\_C\_F_{fc} + \beta\_N\_F_f * CP\_N\_F_{fc} \tag{2}$$

$\beta\_C\_H_k$: parameter that allows varying THC at the k hub port;
$CP\_C\_H_{kc}$: THC per unit of type c container at the k hub port;

$\beta\_N\_H_k$: parameter that allows varying port dues at the k hub port;
$CP\_N\_H_{kc}$: port dues per unit of type c container at the k hub port;
CP_H_{kc}: port costs of the k hub port per unit of type c container as defined in the following equation:

$$CP\_H_{kc} = \beta\_C\_H_k * CP\_C\_H_{kc} + \beta\_N\_H_k * CP\_N\_H_{kc} \tag{3}$$

$\beta\_C\_W_m$: parameter that allows varying THC in the m region of the world;
$CP\_C\_W_{mc}$: THC per unit of type c container in region m;
$\beta\_N\_W_m$: parameter that allows varying port dues in region m;
$CP\_N\_W_{mc}$: port dues per unit of type c container in region m;
CP_W_{mc}: port costs in region m per unit of type c container as defined in below:

$$CP\_W_{mc} = \beta\_C\_W_m * CP\_C\_W_{mc} + \beta\_N\_W_m * CP\_N\_W_{mc} \tag{4}$$

$\alpha\_F\_H\_M$: economies of scale in the route between feeder port and hub port;
$CVU\_F\_H\_M_c$: vessel daily costs per unit of type c container between feeder and hub port;
$SPPED\_F\_H$: vessel speed (knots) between feeder- and hub port;
$DIST\_F\_H\_M_{fk}$: distance (nautical miles) between the f feeder port and the k hub port;
$CV\_F\_H\_M_{fkc}$: sea costs between f and k for type c container as defined in below:

$$CV\_F\_H\_M_{fkc} = \alpha\_F\_H\_M * CVU\_F\_H\_M_c * \left(\frac{DIST\_F\_H\_M_{fk}}{24 * SPEED\_F\_H}\right) \tag{5}$$

$CO\_F\_H\_M_{fkc}$: total costs (ie port costs and sea costs) between f and k for type c container as defined bellow;

$$CO\_F\_H\_M_{fkc} = CP\_F_{fc} + CV\_F\_H\_M_{fkc} + CP\_H_{kc} \tag{6}$$

$\alpha\_F\_H\_R$: economies of scale in road trasport between feeder and hub port;
$CVU\_F\_H\_R_c$: cost per kilometre per unit of type c container shipped by road between feeder and hub port;

$DIST\_F\_H\_R_{fk}$; road distance (in kilometres) between f and k;
$CV\_F\_H\_R_{fkc}$: road transport cost between f and k, for type c container as defined in the following equation:

$$CV\_F\_H\_R_{fkc} = \alpha\_F\_H\_R * CVU\_F\_H\_R_c * DIST\_F\_H\_R_{fk} \tag{7}$$

$CO\_F\_H_{fkc}$: minimum cost operation between f and k, for type c container (between maritime and road transport), as defined in the equation below:

$$CO\_F\_H_{fkc} = \min(CO\_F\_H\_M_{fkc}, CV\_F\_H\_R_{fkc}) \tag{8}$$

α_H_W: economies of scale in the route between hub ports and destination regions;
$CVU\_H\_W_c$: vessel daily costs per unit of type c container between hub ports and destination regions;
$SPEED\_H\_W$: vessel speed (knots) between hub ports and destination regions;
$DIST\_H\_W_{km}$: distance between the k hub port and the m destination area;
$CV\_H\_W_{kmc}$: sea costs between k hub and m destination, for type c container, as defined in the following equation:

$$CV\_H\_W_{kmc} = \alpha\_H\_W * CVU\_H\_W_c * \left(\frac{DIST\_H\_W_{km}}{24 * SPEED\_H\_W}\right) \tag{9}$$

$CO\_H\_W_{kmc}$: total costs (ie port costs and sea costs) between k hub and m destination, for type c container, as defined in below:

$$CO\_H\_W_{kmc} = CP\_H_{kc} + CV\_H\_W_{kmc} + CP\_W_{mc} \tag{10}$$

TCO_{fkmc}: total 'network' cost from f feeder port, through k hub port, to m destination area, for type c container, as shown in below:

$$TCO_{fkmc} = CO\_F\_H_{fkc} + CO\_H\_W_{kmc} \tag{11}$$

Decision variables:

Y_k: binary variable that shows location or non-location for k hub port;
X_{fkmcs}: flow fraction from the f feeder port to the m destination area, through the k hub port, and for type c container with s direction.

Objective function:
Total cost (TC) minimization

$$TC = \sum_{f=1}^{F} \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{c=1}^{C} \sum_{s=1}^{S} TCO_{fkmc} * X_{fkmcs} * Q_{fmcs} \quad (12)$$

Subject to:

$$\sum_{k=1}^{K} Y_k = N \text{ (}N \text{ defines the exact number of hub ports that must be open)} \quad (13)$$

$$Y_k = \begin{cases} 1 & \text{if location } k \text{ is a } \textit{hub port} \\ 0 & \text{otherwise} \end{cases} \quad \text{for all } k \quad (14)$$

$$0 \leq X_{fkmcs} \leq 1 \quad \text{for all } f, k, m, c, s \quad (15)$$

$$\sum_{k=1}^{K} X_{fkmcs} = 1 \quad \text{for all } f, m, c, s \text{ (ie each } f \text{ to } m \text{ flow passes through a } k \text{ hub)} \quad (16)$$

$$X_{fkmcs} \leq Y_k \quad \text{for all } f,\ k,\ m,\ c,\ s \quad (17)$$

Entry data

Feeder ports and hub port candidates are assumed to constitute a single set. This expands the level of analysis. Detailed analysis has been carried out earlier by Aversa (2001) and Costa (2001) on the differences among South American East Coast ports, in terms of handling capacity (comparisons of the number and type of equipment (transtainers; portainers; toploaders; and reachstackers) and the number and extension of berths available at containers terminals).

Tables 3 and 4 present container flows and costs, at the ports considered in this analysis. Port costs of empty containers have been assumed to be half of those full. It is also assumed (which is close to reality) that Brazilian ports do not differentiate between TEU and FEU costs.

Road and shipping costs

Another defined parameter was road transport costs (*CVU_F_H_R*) per container between feeder and hub ports. From earlier studies (see also

Haralambides and Londoño-Kent, 2004), an average of US$1 per kilometre has been assumed. No differentiation was made between TEU and FEU (as it is the same road vehicles that carry both).

The parameters of vessel daily operating costs per container (including fuel costs) between feeder- and hub port (*CVU_F_H_M*), and between hub port and world region (*CVU_H_W*) were taken from data reported in Decker and Hamburg (2001). On the basis of these data, Figure 3 depicts economies of scale achieved in liner shipping for geared and gearless vessels up to 4,000 TEU.

Both geared (smaller) and gearless (larger) vessels are deployed in the East Coast of South America: the former – vessels from 800 to 1,500 TEUs- are used in the coastal trades of the Brazilian coast, where onboard gear is often necessary in operations. Vessels larger than 1,500 TEUs can be used in international long-distance shipping. An average speed of 18 knots is assumed for the former vessels (*SPEED_F_H*), and 20 knots for the latter (*SPEED_F_H*).

Table 5 shows the parameters of daily operating costs of vessels considered in this study. The cost of carrying one FEU is assumed to be double that of one TEU, while no distinction is made between the cost of transporting full or empty containers (as they both occupy one slot).

Table 3: Container flows at ports in the East Coast of South America

	Import				Export						
Units	**FCL_20**	**FCL_40**	**EMP_20**	**EMP_40**	**FCL_20**	**FCL_40**	**EMP_20**	**EMP_40**	**Full TEU**	**Empty TEU**	**Total TEU**
SSZ	41.021	26.037	1.678	1.661	40.371	20.175	2.328	7.523	173.816	22.374	196.190
BUE	24.885	22.058	1.531	773	20.041	13.948	6.375	8.883	116.938	27.218	144.156
SFS	5.304	1.958	4.094	8.438	9.394	10.392	4	4	39.398	20.982	60.380
RIG	3.960	2.005	338	8.317	3.964	10.318	334	4	32.570	17.314	49.884
PNG	3.635	7.668	152	221	2.345	5.358	1.442	2.531	32.032	7.098	39.130
RIO	8.517	4.047	2.592	149	10.981	2.155	128	2.041	31.902	7.100	39.002
SUA	3.779	2.770	328	566	2.802	3.272	1.305	64	18.665	2.893	21.558
SSA	1.826	1.452	2.300	1.091	4.122	2.539	4	4	13.930	4.494	18.424
FOR	405	275	1.843	948	2.202	1.145	46	78	5.447	3.941	9.388
MVD	1.791	1.274	4	4	887	615	908	663	6.456	2.246	8.702
SEP	4	4	4	4	4	4	4	4	24	24	48
Total	95.127	69.548	14.864	22.172	97.113	69.921	12.878	21.799	471.178	115.684	586.862

Source: Costa (2001).
EUR: Northern European ports (the Port of Rotterdam in The Netherlands is selected for distance calculation purposes). MED: Mediterranean ports (the Port of Genoa in Italy is selected for distance calculation purposes). AMN: Canada and US ports (except Gulf of Mexico. The Port of New York is selected for distance calculation purposes). CAR: Central America and Gulf of Mexico ports (the Port of Kingston in Jamaica is selected for distance calculation purposes. FOR: Port of Fortaleza. SUA: Port of Suape. SSA: Port of Salvador. RIO: Port of Rio de Janeiro. SEP: Port of Sepetiba. SSZ: Port of Santos. PNG: Port of Paranaguá. SFS: Port of São Francisco do Sul. RIG: Port of Rio Grande. MVD: Port of Montevideo. BUE: Port of Buenos Aires. FCL_20: full TEU. FCL_40: full FEU. EMP_20: empty TEU. EMP_40: empty FEU.

Table 4: Port costs in US$/unit

US$/unit	Terminal handling charges				Port dues			
Port code	FCL_20	FCL_40	EMP_20	EMP_40	FCL_20	FCL_40	EMP_20	EMP_40
EUR	96.00	120.00	48.00	60.00	5.00	5.00	2.50	2.50
MED	125.00	155.00	62.50	77.50	5.00	5.00	2.50	2.50
AMN	415.00	550.00	207.50	275.00	75.00	100.00	37.50	50.00
CAR	100.00	125.00	50.00	62.50	5.00	5.00	2.50	2.50
FOR	135.91	135.91	67.96	67.96	47.11	47.11	23.56	23.56
SUA	108.94	108.94	54.47	54.47	47.57	47.57	23.79	23.79
SSA	138.40	138.40	69.20	69.20	52.35	52.35	26.18	26.18
RIO	143.67	143.67	71.84	71.84	28.79	28.79	14.40	14.40
SEP	124.93	124.93	62.47	62.47	20.57	20.57	10.29	10.29
SSZ	166.57	166.57	83.29	83.29	27.43	27.43	13.72	13.72
PNG	127.23	127.23	63.62	63.62	52.38	52.38	26.19	26.19
SFS	109.07	109.07	54.54	54.54	40.85	40.85	20.43	20.43
RIG	146.52	146.52	73.26	73.26	37.77	37.77	18.89	18.89
MVD	130.00	150.00	65.00	75.00	15.00	15.00	7.50	7.50
BUE	120.00	140.00	60.00	70.00	15.00	15.00	7.50	7.50

Source: GEIPOT (2000).
See footnote in Table 3.

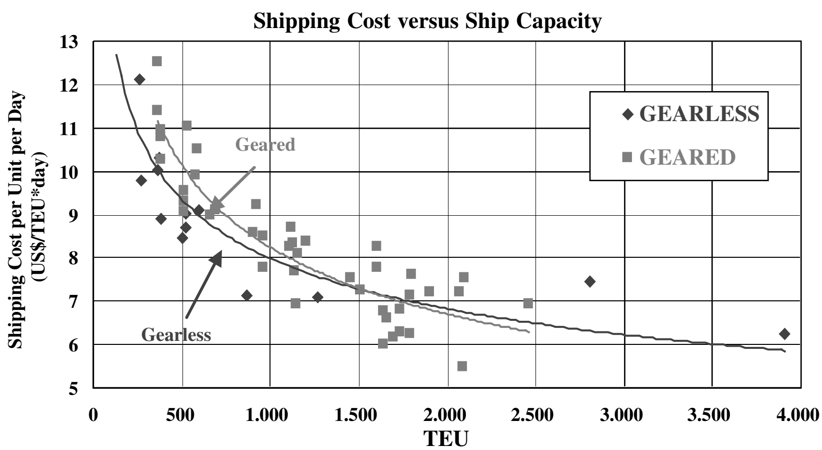

Figure 3: Economies of scale in liner shipping

RESULTS

The model was run with the General Algebraic Modelling System (GAMS) program (Brooke, Kendrik and Meeraus, 1997), with the CPLEX and the OSL

Table 5: Vessel daily operating costs (including fuel costs)

US$/unit day Parameter	Shipping unit costs FCL_20	FCL_40	EMP_20	EMP_40	Vessel capacity TEU
CVU_F_H_M	8.5	17.0	8.5	17.0	800-*Geared*
CVU_H_W	7.5	15.0	7.5	15.0	1.500-*Geared*

resolution algorithms. These algorithms are appropriate for linear, integer, and mixed linear programming problems, while other algorithms, like ZOOM and MINOS, are applicable for non-linear models.

The model includes 11 feeder ports (FOR, SUA, SSA, RIO, SEP, SSZ, PNG, SFS, RIG, MVD, BUE) which, as mentioned above, are also hub port candidates. Also, four world regions are considered (EUR, MED, AMN and CAR); four types of containers (FCL_20, FCL_40, EMP_20 and EMP_40); and two flow directions (import and export). As a result, the model contains 3,883 decision variables and 4,225 constraints. *The port of Santos was selected as the optimal solution, with a total cost of US$ 295 million*.

A number of interesting observations can be made from Table 6 and the derived Figure 4. in all, 30% of total costs are related to feeder costs, that is, shipping and port costs in the port system of the East Coast of South America. The remaining 70% refers to 'mainline costs', that is, ocean transportation to world regions and related port costs at both ends. Total 'hub costs', that is, feeder plus mainline, add up to 39%, making this the single most important cost item of the system. The greatest part of the latter costs (see also Table 4) regards THC and this explains carriers' keen interest in dedicated container terminals (Haralambides *et al*, 2002). These figures come also in stark contrast to the often 'politically proclaimed' arguments that port costs in general represent only a small portion of overall transport costs: Total port costs, that is, hub and world port costs, amount to 82% of total system costs, with shipping costs representing 18% only.

Scenarios and sensitivity analysis

Next, the constraint $N=1$ is relaxed and the model is allowed to allocate an increasing number of hubs, up to 11, which is the total number of feeder ports considered in this study. The objective is to investigate the impact of such allocations on total system costs, as well as the sensitivity of such allocations to changes in shipping and port costs.

Table 6: Cost break down of optimal solution: Port of Santos

	Costs	10^6 US$	%
Feeder	Feeder port costs	37.3	13
	Shipping costs (feeder- to hub port)	5.1	2
	Hub port costs	45.3	15
	Total feeder costs	87.7	30
Main line	Hub port costs	71.3	24
	Shipping costs (hub to world region)	48.1	16
	World region port costs	87.9	30
	Total main line costs	207.3	70
	Total costs	295.0	100

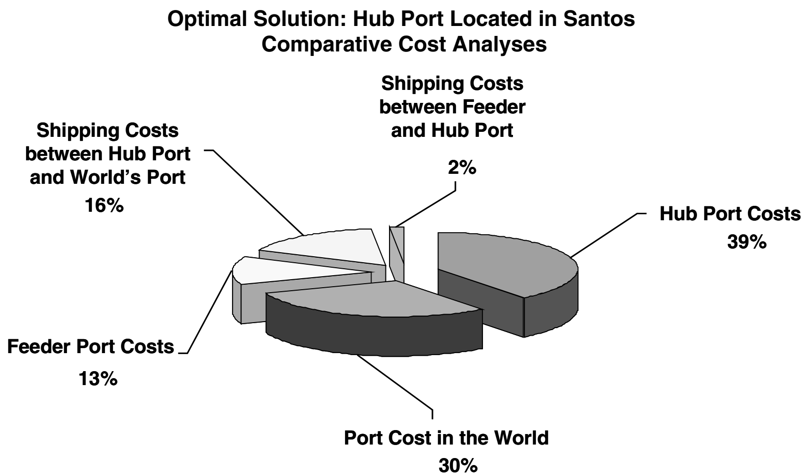

Figure 4: Cost break down of optimal solution: Port of Santos

Figure 5 and Table 7 show that, as the number of hub ports gradually increases to 11, total system costs decrease. Apparently, as we move towards multi-porting, feeder costs decline while mainline costs remain fairly constant. The single hub configuration is thus shown to be 46% more costly than the reference case scenario of no hub ($N11=100$) (Table 7). In the margin, that is, when $N=11$, there is no transhipment hub and all cargoes are shipped to final destination directly *via* the 'own' origin port.

Table 7 also shows the order of increasing the number of hubs: $N=1$ (Santos); $N=2$ (Santos and Buenos Aires); $N=3$ (Santos, Buenos Aires and Sao Francisco do Sul); and so on. Comparing this ordering with that of Table 3, where ports are ordered only on the basis of container flows, one can observe that, as of the fourth position, the ordering is different (note particularly the importance of Rio de Janeiro, as a hub, despite its comparatively low traffic volume). Apparently, and this is the added value of our model, other parameters (ie shipping and port costs) play a role equally important to that of container flows in the attractiveness of a port as a hub.

Consequently, an attempt is made to establish the required decreases in shipping and port costs, necessary in order to achieve total system cost down to the level of reference case scenario ($N=11$). This is done for two cases: (a) optimum solution ($N=1$, Santos); (b) $N=2$ (Santos and Buenos Aires). Four scenarios were considered in each case (Table 8) and the results appear in Table 9.

Case (a): As was to expected, a modest (12–13%) decrease in shipping costs alone has a very small impact on total system costs (2.3%). This result remains fairly the same even when the decrease in shipping costs almost doubles (20%), although, interestingly enough, Buenos Aires now becomes the optimal solution (single hub). In both instances, port costs have to be reduced by roughly 35% to achieve overall system savings down to the level of reference case scenario (202 millions; $N=11$).

The results of case (b) are fairly similar. A two-hub configuration, however, achieves a total saving (compared to $N=1$) of 14.8% by itself. Thus, although here also shipping costs have a small impact, only a 20% reduction in port costs is required to bring down overall system costs to the level of reference case.

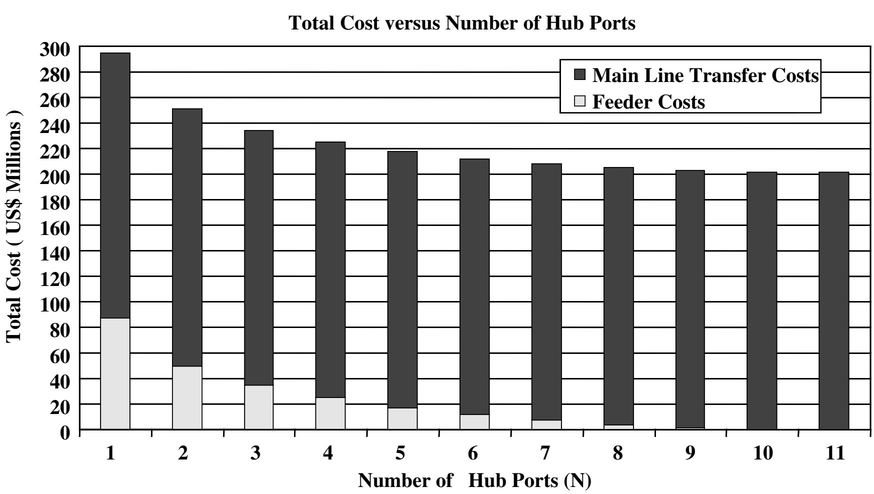

Figure 5: Total cost *versus* number of hub ports

Table 7: Model results

No. of hubs	Total costs 10^6 US$	% (base: $N=11$)	Feeder costs 10^6 US$	Transshipment costs 10^6 US$	% of feeder costs %	% of Trans-shipment costs %	Hub ports FOR	SUA	SSA	RIO	SEP	SSZ	PNG	SFS	RIG	MVD	BUE
1	295	146	88	207	30	70						X					
2	251	125	50	201	20	80						X					X
3	234	116	35	199	15	85						X		X			X
4	225	112	25	200	11	89				X		X		X			X
5	218	108	17	201	8	92				X		X		X	X		X
6	212	105	12	200	5	95		X		X		X		X	X		X
7	208	103	7	201	4	96		X	X	X		X		X	X		X
8	205	102	4	201	2	98		X	X	X		X	X	X	X		X
9	203	101	2	201	1	99	X	X	X	X		X	X	X	X		X
10	202	100	0	202	0	100	X	X	X	X		X	X	X	X	X	X
11	202	100	0	202	0	100	X	X	X	X	X	X	X	X	X	X	X

Table 8: Scenario description

Scenario	Description
S_*_I	Decrease of around 10% in feeder and mainline costs
S_*_II	Decrease of around 20% in feeder and mainline costs
SP_*_I	Decrease of around 10% in feeder and mainline costs and, simultaneously, decrease port costs to achieve reference value (202 million; $N=11$)
SP_*_II	Decrease of around 20% in feeder and mainline costs and, simultaneously, decrease port costs to achieve reference value (202 million; $N=11$)

* = 1, 2.

Table 9: Scenario results

		Decrease in shipping costs					
Scenario	Number of hub ports	Mainline (%)	Feeder (%)	Decrease in total port costs %	Total cost US$ millions	Decision Hub port(s)	Savings %
Actual_1	$N=1$	—	—	—	295	Santos	—
S_1_I	$N=1$	12	13	—	288	Santos	2.3
SP_1_I	$N=1$	12	13	36	201	Santos	31.8
S_1_II	$N=1$	21	20	—	283	Buenos Aires	3.9
SP_1_II	$N=1$	21	20	34	202	Santos	31.5
	$N=2$	—	—	—	251	Santos Buenos Aires	14.8
S_2_I	$N=2$	12	13	—	244	Santos Buenos Aires	17.3
SP_2_I	$N=2$	12	13	22	201	Santos Buenos Aires	31.8
S_2_II	$N=2$	21	20	—	240	Santos Buenos Aires	18.7
SP_2_II	$N=2$	21	20	20	201	Santos Buenos Aires	31.9
	$N=11$	—	—	—	202	all	31.7

Finally, this last section of the paper presents the minimum independent (ie *Ceteris paribus*) improvements in traffic flows and port costs that are necessary if the ports of Buenos Aires, Sepetiba, and Suape were to achieve single-hub status. For Buenos Aires, this can be achieved by: a 5% increase in demand (151,000 TEUs) or a 2% decrease in port dues or a 3% decrease in THC. In the case of Sepetiba single-hub status can be achieved by: increasing full container traffic (imports and exports) to 41,000 TEUs (70%) or decreasing port dues by 11% or decreasing THC by 13%. With regard to the port of Suape, the required increase in container flows (all types) reaches 350%; alternatively, single-hub status could be achieved by a 20% decrease in port dues or a 28% decrease in THC.

CONCLUSIONS

Centrality, high volumes of domestic (ie captive) traffic, good hinterland connections, adequate feedering networks, good infrastructure and competitive port pricing have often been considered as the most important factors if a port is to achieve hub status, that is, to be able to handle a significant volume of transhipment containers over and above its local base.

Centrality in particular, in other words minimisation of transport costs, is often given unwarranted significance, usually by 'awkward' river ports, such as Antwerp and Hamburg, while the importance of port costs, in these ports, is at the same time purposely downplayed. This paper has refuted both perceptions: With due regard and caution to the model's assumptions, limitations and need for further refinement, we have shown that shipping costs represent only 18% of total system costs, with the remainder consisting of port costs, predominantly THC. Among others, this explains the carriers' keen interest in developing or controlling dedicated terminal facilities.

Amidst intensified port competition and in view of the 'footloose' nature of the 'container', a port's hub status cannot be taken for granted, as the Santos-Buenos Aires example has demonstrated. Continuous efforts are thus required on behalf of port management to offer efficient and competitive services in a multitude of areas comprising the overall 'port service'.

By assessing simultaneously the impact of traffic flows; port and shipping costs on a port's hub status, this paper offers the basis for a decision tool suitable for the analysis of any port aspiring to hub status. Refinements are, of course, necessary to calibrate the model to local circumstances, while other parameters, not dealt with here, such as the increasing need to recover infrastructure costs; structural shifts in trade flows; and bigger ship sizes, could be easily accommodated.

Acknowledgements

This research was supported by the FAPESP scholarship program No. 99/02151-7, which is gratefully acknowledged. We thank Eng. Gustavo Costa, director of HSAC Logistics and two anonymous referees for their constructive comments.

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