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Network Analysis in the Caribbean

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Abstract

The Caribbean region is a cross road of international and regional container traffic. Most of the islands in the region have also adopted ambitious strategies to become prime locations for container transshipment. This paper introduces a tool that can be used to visualise and analyse the Caribbean container flows. The tool is constructed on the basis of a multi-layered graph structure and is highly parameterized to allow for flexible selection of flows and ports. The tool supports the assessment of the potential for the development of logistics and transport hub through the calculation of relevant indicators using available information on container flows in the region. Much of the empirical work centers on the estimation of the origin-destination matrix of container flows in the region. The paper presents a case study for the island of Curacao.

1 Introduction

Transport is generally recognized, together with utility industries and telecommunication, as a network industries. There has been considerable attention in the transport literature about the usefulness of networks as a basis for analysis (see Economides 1996 for a theoretical survey). Many applications to transport problems have also been put forward. Authors such as Mitchell & Smith (2001), Melkote & Daskin (2001), Southworth & Peterson (2000), Garrison (1960), Konings et al (1992), Choi & Jang (2000), Taylor (2000) and Buckwalter (2001) all employ network concepts in one way or another, and apply these to transportation areas such as pedestrian transport, infrastructure, road networks, and intermodal transport.

This paper is an addition to the literature in that is fills a gap between the more theoretical analysis of networks and the existing empirical studies. The problem with the former is that the economic analysis of networks gives little direction for data gathering and empirical analysis, while the problem with the latter is that they usually do not do justice to the complexities and multi-layered nature of transport networks.

The aim of this paper is to describe a layered build-up of a transport network, and the procedures for collecting and constructing the data necessary to analyse this network. The paper focuses in particular on combining information from different levels of the network to calculate indicators on other levels.

The application for this paper is taken from the container shipping industry, more particularly liner shipping in the Caribbean (liner shipping refers to transportation according to fixed schedules). This industry is responsible for transporting containers in and out of the Caribbean region, and between the islands and American countries. The background for this choice was a research project into the potential to develop the Port of Curacao into a regional container hub.

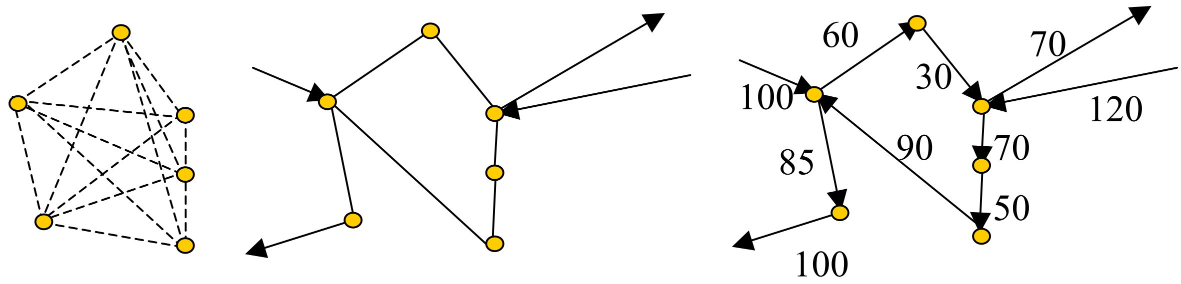
The remainder of this paper is organized as follows. The next section introduces the construction of the compound network that is required to describe the container shipping network in the Caribbean. Section 3 then discusses data collection and construction. Section 4 introduces some network structures that form the basis for the analysis of the network. Section 5 contains some concluding remarks.

2 Network construction

Most applications of network theory in transport start with the observation that the particular transport problem under investigation is characterized by the existence of nodes, and links, and that, therefore, there is a network.

That such a simplification is not adequate has been challenged by a number of authors (see for instance the discussion in Button 1999) in the sense that they point at the existence of physical links and relational links. This paper argues, that a transport network should be described by means of a three-level approach.

The first level is the physical or infrastructural level. In road transport, this is the level of road segments and crossings and in rail transport, it is the stations and tracks between them. The crossings or stations are the nodes, and the road or track segments the links.
In air transport and sea transport, there are only nodes (i.e. the air- and seaports). There are no physical links between airports and between seaports that have the characteristic of a line. One could argue that flight paths and seaways might play this role. However, flight paths and sea ways usually do not cover the full length of the connection, and even then, allow for much more flexibility than roads or rail road tracks.
The second level is the transport level. This is formed by the connections that are actually offered by transport operators. Even though at the infrastructure level, many connections are physically possible, transport operators may not use all of these in their service package. This second level therefore creates a related, but different network on top of the infrastructure network. It is bounded by the existing infrastructure, because it is impossible to offer transportation if the infrastructure is not present.
The third and final level is the service level. This level indicates the quality of the transport connections, in terms of volume, frequency, reliability and so on. This multi-layered network view is illustrated in Figure 1, for the case of international container shipping.



Level 1. Ports Level 2. Liner schedules Level 3. Liner transport

Figure 1: multi-layered network description
(dotted lines indicate potential links)

Each of the levels can be characterized by fairly distinct data sets. The infrastructure level is characterized by distance and capacity, the transport level by a connection matrix, and the third level by a varied set of economic variables, such as volume, price and frequency. For the analysis of a transportation problem, the most interesting level to analysis is obviously this third level. However, on this level, the availability of information that can properly represent the network is limited. This paper argues that some of this information can be reconstructed from information on the other two levels. To summarise, Table 1 lists some of the typical information variables by level.

	Level	**Typical variables**
1	Ports	Traffic, capacity, quay length, draught, nr of cranes, stack space, …
2	Liner schedules	Direct connections by port of call, indirect connections by port of call, nr of ports (by string, by continent), ship capacity, …
3	Liner transport	Volume, frequency, price/tariff, …

Table 1: variables of interest by network level

It is of interest to analyse available data and investigate to what extent this data can be used to develop a full set of data on the third network level. There is one method that is widely used to determine information about the third level from information in the first and second level. This is the estimation of origin-destination matrices by means of the RAS method. An illustration of this method, and an evaluation of its data-requirements follows in the next section.

3 Data Collection

The straightforward analysis of any container shipping network is hampered by the lack of data on the actual transported quantities of containers from a set of origins to a set of destinations. What is available is three sets of data: (1) container port traffic, (2) import and export flows of containerized cargo and (3) vessel movements. Each of these three data sets by themselves lacks crucial information to analyse container transportation. Port traffic data does not give information on origins or destinations. Import and export flows does not include information on routing and mode of transport. This foregoes the added complication that import and export flows are usually reported in dollars, and not in metric tons or the common container measure twenty foot equivalent units (teu). Vessel sailing information does not contain information on volumes, but only on the movements of ships.

The two most useful of these three data sets are the port traffic and the vessel movements, because they are reported in teus, and can thus be used without any recalculation. The container port traffic information can be found from a web-data service such as Containerisation International, and the vessel movements can be obtained from a company called Lloyd's Maritime Intelligence Unit (LMIU) in London. This company collects the observations on ocean going vessel larger than 1000 gross ton (GT) all around the world. This information is sorted by vessel in such a way that vessel

itineraries can be reconstructed. This allows the identification of direct, as well as indirect connections between ports and canals.
The data set for the present paper was collected in the context of the research project mentioned above.
The container port traffic data in this paper was obtained from the Containerisation International Online web site. The data on the website is quite complete and lacks information on only a few ports, the most important of which are the ports in Cuba. For these missing ports, alternative sources were investigated, such as development plans, and web sites from port authorities or island governments.
For the ship movements, the data set obtained from LMIU included all ships moving in and out of the Caribbean region. The ship movement database contains information on 8441 vessels and their ports of call in the year 2001. Given that the data set contains all types of vessels, and for the current research only the merchant vessels capable of carrying containers are of interest, all non merchant and non-container vessels where removed from the data set.
The Caribbean region was taken to include all islands in the Caribbean, as well as all the coast lines of countries bordering the Caribbean sea. Furthermore, some further coastal areas where included, such as Brazil, Colombia, and the West Coast of Mexico and South America. The data set contained about 7000 different ports of call, a large number of which however, refer to similar ports or areas but by different names. For a number of locations (for instance, US West Coast) separate ports of call were merged into one location for easier handling. A translation was made from the ship by ship entries to a representation in an origin destination matrix that contains unity if there is a connection, and zero if not. The areas/ports used are shown in Table 2. Panama Canal crossings can be identified separately in the data base but are not included in the O/D matrix.

Europe & Africa	Cuba	American Virgin Islands	West coast, Mexico
Asia & Oceania	Dominica	British Virgin Islands	Corpus Christi, USA
North American Pacific	Dominican Republic	Belize	Houston, USA
North American Atlantic	Grenada	Costa Rica	Miami, USA
South American Pacific	Guadeloupe	El Salvador	New Orleans, USA
South American Atlantic (Non-Caribean)	Haiti	Puerto Barrios, Guatemala	Barranguilla, Colombia
Curacao	Jamaica	Puerto Quetzal, Guatemala	Cartangena, Colombia
Aruba	Martinique	Santo Tomas de Castilla, Guatemala	Santa Marta, Colombia
Bonaire	Montserrat	Honduras	French Guiana
Netherlands Antilles	Puerto Rico	Nicaragua	Guyana
Anguilla	St. Kitts-Nevis	Panama	Suriname
Antigua & Barbura	St. Lucia	Altramira, Mexico	La Guira, Venezuela
Bahamas	St. Vincent & Grenadines	Progresso, Mexico	Maracaibo, Venezuela
Barbados	Trinidad & Tobago	Tampico, Mexico	Puerto Cabello, Venezuela
Cayman Islands	Turks & Cailos Islands	Veracruz, Mexico	

Table 2. Regions and ports in the origin destination matrix

On the basis of the port traffic data and the connection matrix, a full container flow matrix can be estimated using the so-called RAS method. In the literature, this RAS method is the solution of a bi-proportional constrained matrix problem (Bacharach 1970). Bacharach defines this problem as follows:

> Find a matrix A^B such that:
> $A^B \geq 0$ (all matrix elements larger or equal to zero)
> $iA^B = V$
> $A^B i = U$
> $A^B = \lim_{t\to\infty} \langle R^t \rangle A_{t-1} \langle S^t \rangle$,
> where $A_t \geq 0\ \forall\ t$, $V>0$, $U>0$

V, U are the column and row sums, i is a summation vector and $\langle R^t \rangle$ and $\langle S^t \rangle$ are diagonal matrices with the respective vectors R^t and S^t as their diagonal and zeroes everywhere else. The matrix A_0 is the starting or connection matrix[1]. The combination of the R, A and S matrix gives the method its name. The solution matrix A^B can be found by performing an iterative procedure where the matrix A is first premultiplied by R^t and then post multiplied by S^t, and so on until convergence occurs for conditions 2 and 3.
As was mentioned above, the vessel movements database contains the complete itineraries of ships in the Caribbean. That means that many possible connection matrices could be constructed, consisting of indirect connections between areas. For instance, an itinerary from A → B → C → D → A gives direct connections from A to B, from B to C, from C to D and from D to A. It also gives first order indirect connections from A to C, from B to D and from C to A. Finally, it gives second order indirect connections from A to D and from B to A. In principle, a correct estimation of container flows from origin to destination would have to take direct and indirect connections into account. The question is, to what degree should these indirect connections be included. In the present paper, the choice was made to include indirect connections for itineraries up to three weeks. Three weeks seemed to be a reasonable maximum on the length of a cross Caribbean container route. This remains an arbitrary choice, however.
Let F be the matrix of flows. Then F is a weighted sum of connection matrices M_i, where i indicates a matrix containing i-th order connections:

$$(1) \qquad F = RAS(W_0 \circ M_0 + W_1 \circ M_1 + W_2 \circ M_2 + W_3 \circ M_3 + W_4 \circ M_4 + \ldots)$$

Here RAS(.) is a function representing the RAS method. The argument for RAS(.) corresponds to the starting matrix A_0. W_i are the weighting matrices for order i, and the order i is determined by the degree of indirect connections, order 0 indicates the direct connections, and ° is the direct matrix product. In principle, the matrices M are related to

[1] In case a starting matrix is not available, the problem can also be seen as an optimisation problem. In that case, the objective function takes the place of the starting matrix. This is a completely different approach, however.

M_0 according to $M_i = M_0^i$. In the current paper, the two alternatives which are investigated are

$$F_{direct} = \text{RAS}(M_0)$$

(2) and

$$F_{3weeks} = \text{RAS}(\sum_{i=0}^{7} W_i \circ M_i)$$

The latter sum is based on the maximum itinerary of 3 weeks. Observation of the data showed that the longest routes contained 8 ports.

A final adjustment to the application of the RAS method was made for the following reason. In its estimation of flows, the RAS method preserves zeroes. It also attributes equal weight to non-zero entries. This means that a connection that was the result of one ship making an incidental journey gets the same weight as a connection by a ferry that makes the journey twice a week. Obviously, the estimations will differ because of the different total in- and out-flows (i.e. the row and column totals), but there is a danger nevertheless that some flows will be over-estimated. The connection matrix was therefore filtered to take out incidental connections. These were defined to be connections that were the result of only one ship sailing.

Table 3 contains some summary statistics for the two origin-destination matrices thus constructed. The flows are measures in twenty-foot equivalent units (teu), because the port traffic data was measured in this unit. TEU is a standard measure for container volume.

connections Incidental sailings	Direct	Direct removed	Direct and indirect	Direct and indirect Removed
Total nr of connections	1,185	875	1,548	1,209
Sailings ex-Curacao	27	19	33	27
Sailings to-Curacao	28	20	40	29
Curacao – Europe (teu)	13,317	17,487	12,954	16,275
Europe – Curacao (teu)	8,814	21,707	7,834	17,098
Asia - Curacao (teu)	18,454	-	16,336	-
Curacao – Venezuela (teu)	412	949	356	706
Venezuela – Curacao (teu)	242	611	214	466

Table 3. Summary statistics estimates flows data

The results in Table 3 lead to a number of observations. In all cases, the inclusion of indirect connections raises the number of connections, and lowers the flows measured in teu. The impact of the inclusion of indirect connections, and the impact of removing incidental connections is quite substantial. The inclusion of indirect connections increased the total number of connections by 30%, while the removal of incidental connections lowers the total number of connections by 20-25%. All in all, this does not lead to a radically different number of total connections 1,185 vs 1,209, but does give a very different pattern of connections. For instance, for Curacao, the direct connections estimate gives connections to North America Pacific, Martinique, Puerto Quetzal and Progresso, which are replaced in the estimate that includes indirect connections by South America Pacific, Altamira, Vera Cruz and Guyana. Both estimates do give 27 out bound connections.

Another illustration of the differences can be seen from the Curacao-Europe vv flows. The inbound flows seem fairly stable across different estimations, while the outbound flows vary wildly. This is due to an incidental connection between Asia and Curacao that gets a substantial weight in the estimations.

These observations indicate that the most complete flow estimation is the one that includes direct and indirect links, with incidental connections removed (the most right hand side column in Table 3). This data set will be used in the remainder of this paper.

The application of RAS method with different inputs still does not solve some of the information gaps in the data. One such gap is the question if one-time sailings are really incidental or not. To know this, one has to have more information on particular sailings. Another question is the exact routing of the flows. The routing of vessels is known, but what remains unknown is the exact routing of containers via indirect connections. This is in fact a question about the exact form of the weighting function in (1). Finally, there is the importance of the transshipment of cargo. This aspect has not been addressed at all so far. It concerns the indirect routing of cargo where containers are moved from one ship to another in some intermediate location (called the transshipment port). One could amend (1) as follows:

$$(3) \qquad F = \text{RAS}(T \circ M_T + W_0 \circ M_0 + W_1 \circ M_1 + W_2 \circ M_2 + W_3 \circ M_3 + W_4 \circ M_4 + \ldots)$$

Here, T is the weighting matrix for transshipped cargo, and M_T is the corresponding connection matrix. Now $T + \sum_{i=0}^{n} W_i$ is a matrix of ones everywhere. This particular case will not be pursued in the present paper.

This section has shown a way to calculate and estimate additional data on a transport network by combining information from different network layers. The next section will employ a similar approach to the analysis of network structure and hub potential.

4 Network Models

The knowledge we have at this point can be used to analyse the potential redirection of flows and the resulting growth potential of ports. Remember from Figure 1, that we

know the ports in the Caribbean region, and the actual connections between them (from the sailings data) and the estimated volumes of containers on these connections.
We are interested to evaluate if certain ports may in the future develop into a regional transshipment center. This is beneficial for the port and the island because transshipment activities go hand in hand with other economically beneficial activities such as logistics services, trade and other value added activities. One prerequisite for such a development is the position of the port vis-à-vis the network of regional container flows. Below most of the analysis will focus on Curacao, but the analysis equally applies to other Caribbean ports/islands.
The approach towards this analysis is the identification of a so-called promising network sub-structure in the transport network. This structure contains the hub, some existing connections, and flows the hub might want to attract. In other words, it is a construct at the third network level. To obtain an assessment of potential, it will use information from the second network level (other existing connections). A core element of the structures is depicted in Figure 2. This structure is called a path-non-circuit.

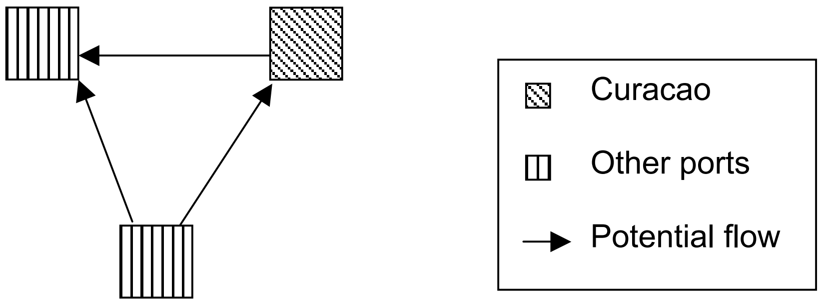


Figure 2. Core network sub-structure

The key item in this structure is that there exist two routes from one port to another port: one direct and one via Curacao. We can infer from the vessel movement database that these connections do indeed exist. There exists a certain distribution of container flows over these two routes. In case Curacao develops its hub activities, it might be able to influence this distribution in such a way, that more containers take the indirect route via Curacao.
We discuss two network structures that allow the identification of hub port potential. These are called the sub-network model and the bypass-network model. Each will be discussed in some detail below.

4.1 The Sub-Network Model

The sub-network model is based on the identification of sub networks. Such a sub-network contains nodes representing Curacao and several ports in the immediate vicinity. This is based on the idea that the Port of Curacao competes most with ports in the immediate neighbourhood. Flows into the whole sub-network display therefore the highest potential, from Curacao's point of view, to be diverted via Curacao. The main parameter to identify vicinity is distance. The parameterisation approach follows the network stage structure as described in Figure 1.
For the selection of ports that are part of this sub-network the following criteria apply.

The port must be connected with Curacao with a flow greater then some constant CPF.
The total port traffic of the port must be greater than some constant TT.
The distance of the port to Curacao must be smaller than some constant D.
For the selection of the flows between ports of the sub-network, the following criteria apply:
If, for a connection, one of the ports is Curacao then the flow on the connection must be greater then some constant CFF.
Between ports in the sub-network (not Curacao), the flow must be greater than some constant SF.

The subnetwork thus established represents the natural trading partners for Curacao, as well as its competitors in terms of logistics service provision. Interesting flows for the cargo hub Curacao are flows from outside the subnetwork to any of the ports in the subnetwork. Cargo hub opportunities lie in the grouping of cargo and in the development of value added services in Curacao.
For the selection of non-sub-network ports that may generate the mentioned interesting flows, the following criteria apply.

The amount of flow on the connection between the port and Curacao must be greater than some constant COF.
The amount of flow on the connection between the port and a port (non Curacao) in the sub-network must be greater than some constant OF.

The sub-network model is depicted in Figure 3 below.

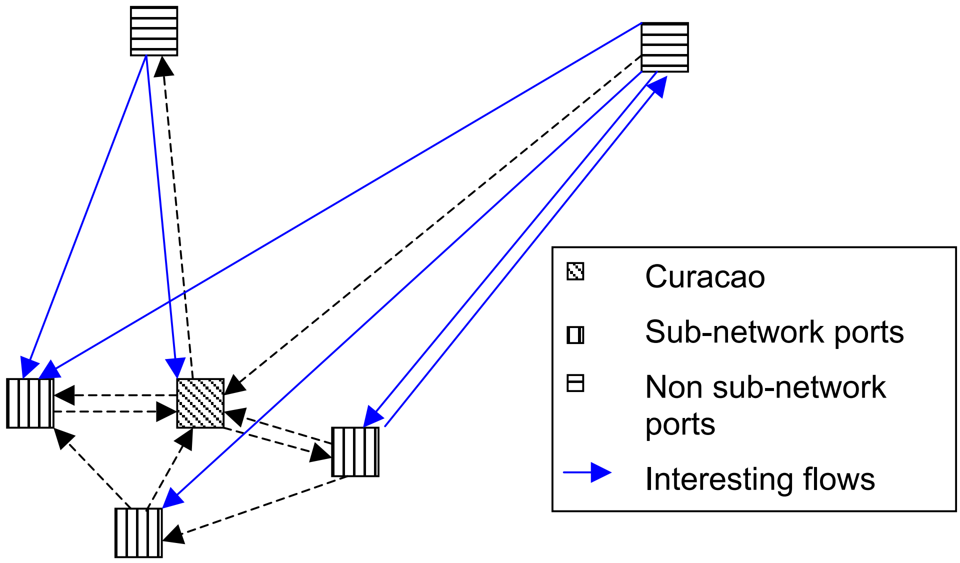


Figure 3. The sub-network model

Table 4 contains some outcomes of the model for various values of the parameter. The potential is calculated by adding the teu of the flows marked with * in the Figure 1.

Case	TT	D	CPF	CFF	SF	COF	OF	Total Volume	Potential	Average degree
1	1	250	1	1	1	all	all	359,995	313,530	8.88
2a	50,000	250						342,332	301,953	6.80
2b	100,000	250						306,915	269,342	5.52
3a		250	250					304,142	256,993	5.60
3b		250		250				295,440	249,435	5.68
3c		250	250	250				294,458	250,489	5.12
4a		250			250			359,001	313,530	7.92
4b		250	250		250			303,922	256,993	5.44
4c		250		250	250			294,449	249,435	4.72
4d		250	250	250	250			294,238	250,489	4.96
5a		250				1 to 10,000		163,085	137,744	8.83
5b		250				> 1000		309,323	267,719	10.00
6a		250					1 to 10,000	137,124	90,659	8.48
6b		250					> 1000	346,334	300,267	6.95
7	50,000	250	250	250	250	1 to 10,000	1 to 10,000	74,073	61,989	4.87

Table 4. Analyses of Sub-Network Model with a small sub-network

The potential in the Table is the total teu of all flows into the non-Curacao ports in the sub-network. It was already mentioned before that this is the absolute maximum potential. What can be realised from this potential is strongly dependent on the

attractiveness of Curacao as a hub and the marketing effort of logistics officers of Curacao based logistics facilitators (port, airport, logistics service providers). Degree is the average number of connections in each node of the network. A lower degree implies a less connected network.
The distance of 250 miles was chosen rather arbitrarily. The base case leads to a sub-network that includes Aruba, Bonaire, and the Venezuelan ports. Reducing the distance to 100 miles (only Aruba and Bonaire) reduces the potential to 43,210 teu. This clearly indicates the importance of the Venezuelan ports for the development of activities on Curacao. It should at least attract some of the flows that now go into Venezuela.
The Table shows that either the parameter CPF or CFF has a large impact on the density of the network, and somewhat less on potential. This is as expected given that these parameters remove entire ports. These parameters taken together do increase this impact on the density but not on potential. Parameter SF does not seem to have such a strong impact on either potential or density. The impact of the parameters COF and OF are opposite to CPF and CFF: they reduce potential, but hardly influence density. This is because they remove single flows and not entire ports.
Some further analysis of the model shows that the parameter COF, when reduced from an interval of 1-10000 teu to 1-5000 to 1-1000 teu, greatly reduces the potential for Curacao from 137,744 to 82,088 to 45,811 teu. Given that it is much more likely that Curacao attracts some smaller flows, than the large trans-Caribbean flows, this shows that even this admitted overstatement of potential does give realistic estimates.
To overcome the arbitrary choice of 250 miles for the sub-network, other distances are analysed as above in Table 5 and 6.

Case	TT	D	CPF	CFF	SF	COF	OF	Total Volume	Potential	Average degree
1	1	375	1	1	1	all	all	399,475	349,732	11.04
2a	50,000	375						381,802	338,239	9.96
2b	100,000	375						306,915	269,243	5.52
3a		375	250					304,142	259,993	5.60
3b		375		250				297,166	248,301	6.48
3c		375	250	250				294,458	250,489	5.12
4a		375			250			397,517	349,732	9.28
4b		375	250		250			303,922	259,993	5.44
4c		375		250	250			295,208	248,301	4.72
4d		375	250	250	250			294,238	250,489	4.96
5a		375				1 to 10,000		189,265	160,646	11.00
5b		375				> 1000		343,294	298,233	12.17
6a		375					1 to 10,000	163,304	113,561	10.56
6b		375					> 1000	382,446	332,922	8.52
7	50,000	375	250	250	250	1 to 10,000	1 to 10,000	74,073	61,898	4.87

Table 5. Analyses of Sub-Network Model with a medium sized sub-network

Table 5 shows that taking 375 miles for the subnetwork increases the potential of all flows by about 40,000 containers. If we increase the total port traffic to 100,000 the potential is the same as in the smaller sub-network. If we increase the minimum flow from or to Curacao to 250 the potential is also the same as in the small sub-network.

Case	TT	D	CPF	CFF	SF	COF	OF	Total Volume	Potential	Average degree
1	1	600	1	1	1	all	all	1,142,126	946,014	21.03
2a	50,000	600						1,083,906	910,089	17.52
2b	100,000	600						932,892	798,985	12.71
3a		600	250					968,071	808,100	13.79
3b		600		250				983,890	789,615	17.17
3c		600	250	250				957,966	798,596	13.21
4a		600			250			1,135,800	946,014	17.31
4b		600	250		250			967,851	808,100	13.64
4c		600		250	250			977,564	789,615	13.45
4d		600	250	250	250			957,746	798,596	13.07
5a		600				1 to 10,000		508,938	333,950	20.86
5b		600				> 1000		1,055,774	862,760	22.57
6a		600					1 to 10,000	359,272	163,160	19.66
6b		600					> 1000	1,127,684	931,701	19.79
7	50,000	600	250	250	250	1 to 10,000	1 to 10,000	241,767	118,316	12.77

Table 6. Analyses of Sub-Network Model with a big sub-network

Expanding the sub-network to the entire south Caribbean (600 miles) triples the potential of the small sub-network that was represented in Table 4. This sub-network includes the strong neighbour Trinidad & Tobago and the larger island economies of Haiti, Jamaica and the Dominican Republic. Apparently, substantial volumes of interesting flows originate from these areas further away from Curacao. Still, Table 4 also shows that a substantial potential does lie close to Curacao.

4.2 The Bypass Model

The second model is called the Bypass Model. This structure contains pairs of ingoing and outgoing flows of Curacao such that the distance of the route $P_1 \rightarrow \text{Cur} \rightarrow P_2$ via Curacao between the ports P_1 and P_2 does not exceed the direct connection $P_1 \rightarrow P_2$ by more than some constant CS. This is based on the idea that Curacao should be able to attract some flows that pass by Curacao anyway. Other important ports have also developed mostly due to their fortunate location.
The considered flows to and from Curacao must be between constants FCmin and FCmax. Cargo hub potential in this model is identified by the fact that rerouting a direct flow via Curacao increases the distance only by a small amount. The selection of these flows should satisfy the following additional criteria (see Figure 4).

The flow between the port pair is between constants FEmin and FEmax.
The flow between either port of the port pair and Curacao is between constants FCmin and Fcmax.
The difference in distance between the direct and indirect route is smaller then constant CS.

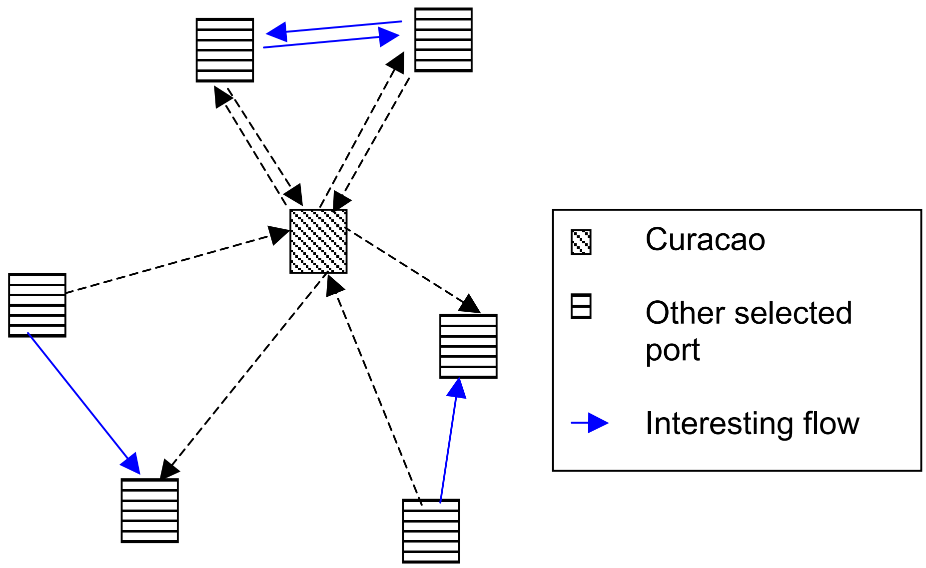


Figure 4. Bypass Network structure

Table 7 gives an overview of the outcomes of the model.

Case	FC	FE	CS	Total Volume	Potential	Average degree
1	all	all	50	754,440	684,509	9.35
1a	1 to 10,000		50	466,204	433,285	8.93
1b	> 1000		50	141,373	132,853	2.00
1c		1 to 10,000	50	199,664	129,733	8.45
1d		> 1000	50	735,595	666,385	6.85
1e	1 to 10,000	> 1000	50	446,928	415,161	6.33
2	all	all	100	870,042	799,827	11.61
2a	1 to 10,000		100	581,806	548,603	11.27
2b	> 1000		100	141,373	132,853	2.00
2c		1 to 10,000	100	241,317	171,102	10.52
2d		> 1000	100	844,772	775,080	8.15
2e	1 to 10,000	> 1000	100	556,130	523,856	7.52
3	all	all	200	1,323,079	1,252,462	13.94
3a	1 to 10,000		200	724,991	691,386	13.44
3b	> 1000		200	162,644	151,365	3.00
3c		1 to 10,000	200	282,203	211,586	12.36
3d		> 1000	200	1,287,555	1,217,578	9.57
3e	1 to 10,000	> 1000	200	689,223	656,502	8.92

In the table, only changed values with respect the base case are depicted.

Table 7. Analysis of the bypass model

The potential in the base case indicates the amount of containers that flow geographically via Curacao from east to west and vice versa through the southern Caribbean. The degree of this network, 9.36 also indicates that a quite dense network of flows going both ways and interlinking many non-Curacao ports. Furthermore, reducing the distance only slowly reduces the potential. In other words, the flows come really close to Curacao. Curacao is located centrally to a large number of flows.

What is apparent, however, is that Curacao does not seem to capture much of this potential at the moment. This can be understood when looking at the current maritime geography (see for instance de Monie 1998 in an ECLAC bulletin). In the ranking of global and regional pivots, and subregional mainports and minor ports, Curacao is at best a sub-regional mainport.

The analysis of the intervals FE and FC shows that capping the flows from above through FE reduces potential much quicker than through FC. This indicates that the flows between any of the non-Curacao ports and Curacao are smaller than the flows between the port pairs. Given the difference in reaction to the parameter change, one could infer that this difference in volume is substantial. The same effect, but in reverse can be observed when the intervals are capped from below. While the capping from below has almost no effect for FE, it immediately reduces potential for FC. Capping FC

from below also severely reduces the density in the network. This shows that currently, the hub activities of Curacao are very limited.
The port pairs can be deduced directly from a glance at a map of the Caribbean. Given that the diversion is limited to a maximum of 50 miles, port pairs should be almost on a straight line through Curacao, except for the ports that are south of Curacao, who are connected with other ports south but on the other side of Curacao through a semi-circular route (for instance Trinidad & Tobago and ports in Columbia).
Again this model shows substantial potential, but when looking at realistic (read: smaller) flows, the potential quickly disappears. The reasoning that the smaller flows are the more realistic ones is that the flows with large volumes are usually governed by the major container shipping companies who will not easily be induced to divert cargo. Smaller, locally operating companies, however, are probably be more susceptible to changing their routes under the right circumstances.

5 Conclusions

This paper has described a multi layered network analysis tool that can be used to assess the potential for developing logistics activities on Curacao. For this analysis, extensive data collection and data processing was necessary. With the help of some concepts from graph theory, two network models were developed that allows the quantification of potential for the logistics hub: the sub-network model and the bypass model. These network models work through the comparison of information between two layers of the network model.
Potential in both these models is measured as the addition of flows between ports outside of Curacao, that may be persuaded to flow via Curacao. This paper assumes that companies on Curacao are ultimately able to actually attract some of these flows. How they should go about this, is outside the scope of this paper. It will be important, however, to attract these flows by offering interesting logistics advantages, such as extended services, time and money savings and possibly multimodal connections between sea and air. Furthermore, this paper does not take into account new flows that may be generated by a logistics service provider choosing Curacao as their Caribbean hub.
The model analysis indicates, in first instance, that there is a large potential for Curacao. This potential, however, can only be reached if many flows in the Caribbean are re-routed through Curacao. This seems unlikely. If variables are capped to more realistic levels, the models show that the potential reduces to a doubling of current port traffic (which is now around 75000 teu) at best. Since currently, the main Curacao port could handle up to 140000 teu without further investment, it seems unlikely that one should recommend port expansion and investment in equipment for the coming five to ten years or so.
The models represent a first effort. Many improvements and additions could be made, including the addition of air transport connections, the inclusion of cost and time effects

of value added activities in the hub Curacao, and the development of other graph models that indicate other potentials which the current two models have not detected. This is left for further research.

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