Port Resilience

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CCICADA

Command, Control, and Interoperability
Center for Advanced Data Analysis

The Importance of Ports

- ***Global Trade critical to US economic well-being***
- >90% of international trade by sea
- Efficient, effective, secure system of ports crucial to international trade
- Ports are also crucial to the national supply chain of critical products: fuel, food, medical supplies, etc.

Vulnerability of Ports

- Considerable effort to introduce data-science-based methods to make our ports safer.
- Other CCICADA efforts on container inspection are part of that.
- Those efforts concentrate on inspection of cargo.
- This project is concerned with ways in which ports might be shut down in part or entirely.

Vulnerability of Ports

- Ports might be shut down by terrorist attacks, natural disasters like hurricanes or ice storms, strikes or other domestic disputes, etc.
- Project themes:
  - ***How do we design port operations to minimize vulnerability to shut down?***
  - ***How do we reschedule port operations in case of a shutdown?***

Vulnerability of Ports

- We are building on our partnerships with the Ports of Los Angeles/Long Beach and Newark/Elizabeth.
- We are building on our partnership with the US Coast Guard.

Rutgers group touring Port of Philadelphia with Coast Guard Sector Delaware Bay

Minimizing Vulnerability to Shutdown

- Understand key elements in port operations: logistics, transportation, security, communications, etc.
- Identify the key vulnerabilities
  - Build on a CREATE project that scaled threat and vulnerability at Port of Long Beach/Los Angeles
- Identify economic consequences of different deliberate or natural “attacks” on ports
  - Build on CREATE’s identification of potential means of attack
- Build scenarios to underlie the analysis in the rest of the project.

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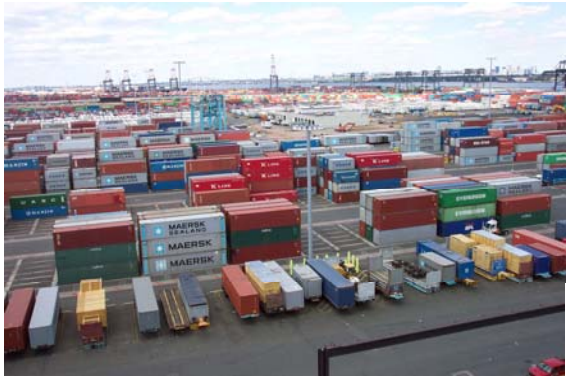
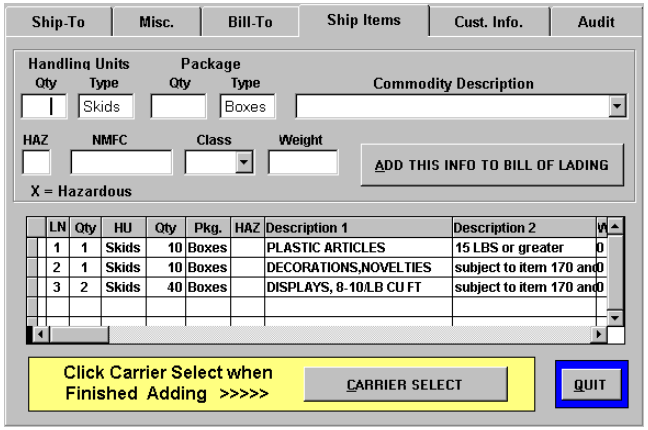
Reopening a Port After Shutdown

- Shutting down ports due to hurricanes is not unusual.
- Scheduling and prioritizing in reopening the port is typically done very informally (per our discussions with Coast Guard).

Manifest Data

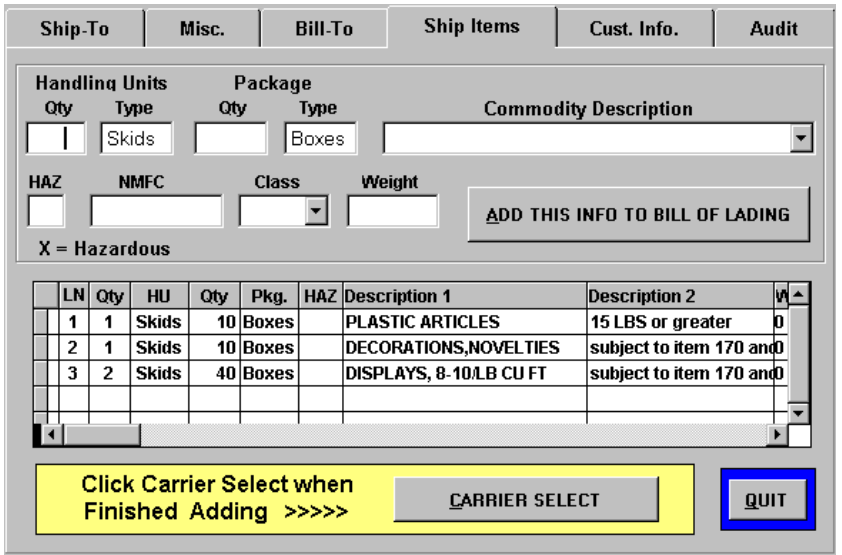
- Part of the solution to the port reopening problem: Detailed information about incoming cargo:
  - What is it?
  - What is its final destination?
  - What is the economic impact of delayed delivery?
- We will use container ***manifest data*** – available through CBP – to estimate economic impact of various disaster scenarios & understand our port reopening requirements
- This involves machine learning and text analysis





Working with Manifest Data

- Manifest/bill of lading
- Data either text or numerical/categorical
- Increased emphasis by US Customs and Border Protection on documents submitted prior to a shipping container reaching the US
- Data screened before ship's arrival in US
- Identifying mislabeled or anomalous shipments may prove useful in finding nuclear materials



Manifest Data

- Overview of Our Manifest Data
  - Source: Customs and Border Protection
  - Earlier work: 2 days' data of all manifests of ships to U.S.
  - New work: one month's data of all such manifests
  - 2-days' data: Size: 99 Megabytes
  - 2-days' data: # of Manifests: 19,038 (repeated records deleted)
  - One manifest can include many containers
  - One container can include many packages

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1APLUUSPRES ADAMS           00186460106120 2APLU054491153   533130000000010 00PKGS 000000202 30KG000000000 26CMDLUDHIANA, IN           861693400100000040PORW
1APZU3102448   APL251813                  G00200000000806000008002 2G0LCY
3AGRO DUTCH INDUSTRIES LIMITED     C/O ABBY FOODS LLC,              1900 THE EXCHANGE SUITE 385,      ATLANTA,GA 30339,USA
4INTERNATIONAL TRADE LOGISTICS,    2525 BRUNSWICK AVENUE,SUITE 200,  LINDEN,NJ 07036,USA
5APZU3102448   00000010006/62 OZ 1000 PACKAGES                                  00000000000000000000 0000000000CANNED MUSHROOMS
5APZU3102448   0000000000TEN KNOCKDOWN EMPTY CARTONS                            00000000000000000000 0000000000INV.NO:ADIL/1121 DT.06/11/2006
5APZU3102448   0000000000PO.NO:A5608093                                         00000000000000000000 0000000000U.S.FDA REGISTRATION NUMBER:
5APZU3102448   0000000000NET.WT.19842.000 KGS                                   00000000000000000000
7APZU3102448   1689173                              TO                                  1690172                                    ;
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Mining of Manifest Data

- Separate effort: Predict risk score for each container
  - Quantify the likelihood of need for inspection
  - Based on covariates/characteristics of a container's manifest data.
- Methods:
  - We are developing machine learning algorithms to detect anomalies in manifest data.
  - Text mining on verbiage fields.
  - Logistic regression with LASSO.
    - Simulation study conducted suggests that the LASSO regression approach is an effective tool for processing information in the manifest data

Resilience Modeling

- If a port is damaged or closed, immediate problem of rerouting some or all incoming vessel traffic.
- Also: problem of prioritizing the reopening of the port.
- These problems can be subtle.
  - Ice storm shuts down port
  - Maybe priority is unload salt to de-ice. It wasn't a priority before.

Resilience Modeling: One Port

- ***Problem: Reschedule unloading of queued vessels.***

Resilience Modeling: One Port

- ***Problem: Reschedule unloading of queued vessels.***
- Think of a ship as corresponding to a vector $x = (x_1,x_2,\ldots,x_n)$ where x_i is quantity of i^{th} good.
- Assume all x_i are integers.
- Suppose for simplicity that each ship takes the same amount of time to unload. Then we can give each ship a ***timeslot*** for unloading.
- The port's capacity determines how many ships can be scheduled at a given timeslot.
- Suppose we require d_i units of good i by timeslot t_i.
- $d = (d_1,d_2,\ldots,d_n)$, $t = (t_1,t_2,\ldots,t_n)$.
- In practice, require d_{i1} units of good i by timeslot 1, d_{i2} units of good i by timeslot 2, etc. Disregard this.
- ***How do we assign ships to timeslots?***

Resilience Modeling: One Port

There are some ***subtleties***:

- The manifest data is unclear. If i is water, $x_i = 48$ could mean 48 bottles of water or 48 cases of bottles of water.
- The manifest data is unclear: Descriptions like "household goods" are too vague to be helpful
- Different goods have different ***priorities***. For example, not having enough food, fuel or medicine is much more critical than not having enough bottles of water.
- Let p_i = the priority assigned to good i, with $p = (p_1, p_2, \ldots, p_n)$.

Resilience Modeling: One Port

There are some ***subtleties***:

- There are ***penalties for late arrivals of goods***.
- Sometimes there are even penalties for early arrivals (storage space issues)
- The penalty can depend on the priorities.

Resilience Modeling: One Port

We encountered a similar problem in working for the Air Mobility Command of the US Air Force.

- Fly soldiers from point A to point B
- Each has desired arrival time
- Getting a general there late is worse than getting a private there late

Similar problems also arise in machine scheduling.

We speak of machine scheduling with earliness and tardiness penalties = "***just in time scheduling***"

Resilience Modeling: One Port

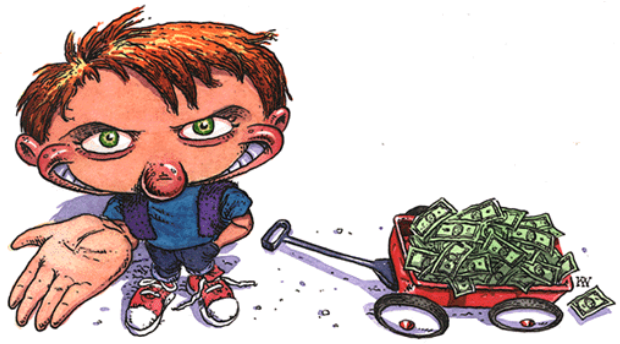
- We have been looking at the simplified problem with all $d_i = 1$ (we demand exactly one unit of each good).
- Then we can talk about the first time a ship carrying good i is scheduled, S_i.
- Let $S = (S_1, S_2, \ldots, S_n)$

Resilience Modeling: One Port

- We are looking at a number of different objective functions F(S,t,p) that need to be optimized.
- Let ***tardiness*** $T_i = \max\{0, S_i - t_i\}$, ***earliness*** $E_i = \max\{0, t_i - S_i\}$.
- For example:
  - $F(S,t,p) = \swarrow p_i T_i + \swarrow p_i E_i$
  - $F(s,t,p) = \swarrow p_i T_i$
  - $F(s,t,p) = \swarrow h(p_i) T_i$
  - $F(s,t,p) = \max\{h(p_1)T_1, h(p_2)T_2, \ldots, h(p_n)T_n\}$

Resilience Modeling: One Port

- A very special case:
  - Only one ship can be unloaded at a time
  - Each ship carries only one kind of good
  - All goods have the same desired arrival time, ♦
- Let $F(S,t,p) = \swarrow h(p_i)T_i$, $h(p_i)$ increasing in p_i.
- Then a ***greedy algorithm*** gives the optimal unloading schedule: Schedule the highest priority good for first arrival, then the second highest priority good,

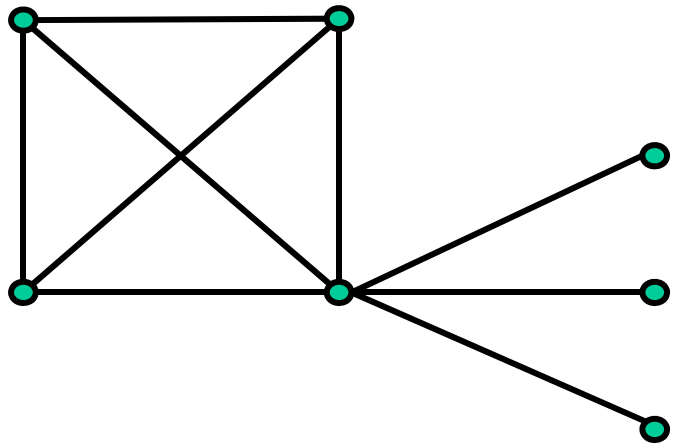


Resilience Modeling: One Port

- Now allow more than one good per ship, but still:
  - Only one ship can be unloaded at a time
  - All goods have the same desired arrival time, ♦
- Let $F(S,t,p) = \swarrow h(p_i)T_i$, $h(p_i)$ increasing in p_i.
- Ship 1 has x = (1,0,0,0), ship 2 has x = (0,1,0,0), ship 3 has x = (0,0,1,1)
- ♦ = 2
- $p_1 > p_2 > p_3 > p_4$
- Now greedy algorithm would take ship 1 first, then ship 2, then ship 3.
- The penalty for this schedule is $h(p_3) + h(p_4)$.
- But: scheduling ship 1 first, then ship 3, then ship 2 has penalty $h(p_2)$, which might be smaller.
- ***The problem is subtle and even in this special case not simple to solve.***

Resilience Modeling: One Port

- Now allow exactly two goods per ship
  - The port has capacity for only one ship at a time.
- This translates into a graph theory problem where ships correspond to edges, goods to nodes, and we want to order the edges in such a way that every node gets assigned a timeslot that corresponds to the earliest timeslot of any edge it belongs to.



Resilience Modeling: Simplifications

- All desired amounts are one unit, i.e., $d_i = 1$, all i.
- Reopened port has limited capacity of one ship per timeslot
- All goods have the same desired arrival time ♦
- All goods have only one desired arrival time rather than portion desired by time 1, some by time 2, etc.
- All ships have same unloading time.
- All ships are ready to dock without delay
- There is no problem storing unloaded by not urgently-demanded goods
- Each ship has only one kind of good

Even making all or most of these assumptions leads to a complex scheduling problem

Resilience Modeling: Rerouting to Nearby Ports

- Problem: If a port can't be reopened soon, we need to assign at least some incoming ships to other ports.
- Goals: minimize economic impact of delay and security impact of delay in delivery of critical supplies.
- Start with one nearby port; then try two ports
- Model ways to set priorities as to where goods will be delivered.

Determining the Priorities

- This needs to be modeled.
- One approach: each stakeholder (government, port operators, shippers) provides their priorities and some ***consensus or voting procedure*** is used to "average" them.

Determining Desired Times for Unloading

- Explore “bidding system” for setting times to unload vessels.
- After government or central entity sets desired times for delivery of critical products, companies receiving shipments make bids for earliest arrival dates.
- Problem is complicated by mixed collection of goods in any container.
- Based on priorities and bids, find ways to do “optimal” rerouting.

Determining Desired Times for Unloading

- The “bidding” system gets into the mathematical analysis of auctions.
- A topic of a great deal of research in mathematics and computer science.
- Information technology allows complex auctions with a huge number of bidders.
- ***Bidding protocols maximizing expected profit can be extremely difficult to compute.***

Determining Desired Times for Unloading

- Multiple goods are to be auctioned off.
- In practice, you submit bids for combinations of goods.
- This leads to NP-complete allocation problems.
- Might not even be able to feasibly express all possible preferences for all subsets of goods.
- Then: Determining the winner of an auction can be extremely hard. (Rothkopf, Pekec, Harstad)

Determining Desired Times for Unloading

- In these complicated "***combinatorial auctions***," we need to elicit preferences from all "players" for all plausible combinations of items in the auction.
- Similar problem arises in optimal bundling of goods and services.
- Elicitation requires exponentially many queries in general.
- Thus, ***bidding procedures to aid in reopening closed ports lead to challenges for modern methods of data analysis.***

Collaborators

- **Reopening Ports**
  - Paul Kantor, Endre Boros, Tami Carpenter, Milind Tambe, Tsvetan Asemov, Emre Yamangil
  - CREATE Center
- **Bidding Systems**
  - Paul Kantor, Aleksandar Pekec

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