How Policy Analytics Leads to Changes “in the Culture”: Examples from “Homeland Security”

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“Changing the Culture”

- Sometimes analytical tools lead to policy recommendations that require changing the way we are used to doing things.
- ***“Changing the culture”***

Credit: uri.edu

Changing the Culture

- We give four examples of use of data science in applications to homeland security
- In each case, policy analytics (data-driven modeling and simulation) led to changes in policy that required changes in the “usual way of operating”: Changes in behavior, attitudes, or other aspects of public policy: ***Changes in the Culture***.

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- CCICADA is the Command, Control, and Interoperability Center for Advanced Data Analysis
- Founded by US Dept. of Homeland Security as a "university center of excellence"
- Based at Rutgers University, but with 17 partner institutions

CCICADA Partners

- Alcatel-Lucent Bell Labs
- AT&T Labs - Research
- City College of NY
- Howard University
- Princeton University
- Rensselaer Polytechnic Inst.
- Texas Southern University
- University of Massachusetts, Lowell
- University of Medicine & Dentistry of NJ
- Applied Communications Sciences
- Carnegie-Mellon Univ.
- Geosemble Technologies
- Morgan State University
- Regal Decision Systems
- Rutgers University (Lead)
- Tuskegee University
- University of Illinois, Urbana Champaign
- University of So.California

CCICADA Works with Many Partners

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- Federal Emergency Management Agency (FEMA)
- US Customs and Border Protection (CBP)
- Transportation Security Administration (TSA)
- FBI
- Centers for Disease Protection and Defense
- US Citizenship and Immigration Service
- Border Patrol
- NJ Office of Homeland Security & Preparedness
- NJ Dept. of Health and Senior Services
- Numerous police departments

Four Examples from Work at CCICADA

- Allocation of Boats to Boat Stations
- Container Inspection at Ports
- Sports Stadium Security
- Nuclear Detection in a City

Example I: Coast Guard Boat Allocation Problem

- We have worked with the US Coast Guard on a variety of projects involving information-based modeling and simulation and other advanced data analysis tools

United States Coast Guard
U.S. Department of Homeland Security

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

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Work with the Coast Guard

Boat Allocation Module (BAM)

- The US Coast Guard has boat stations all around the country
- Each station has different areas of responsibility (missions)
  - Search and rescue
  - Drug interdiction
  - Enforcement of Fisheries Regulations
- There are many types of boats
- Some boats are better at some types of “missions”
- For each station, we have historical data on number of hours required for each type of mission
- Problem: Assign boats to boat stations so number of mission hours required is achieved, but do so “efficiently”

BAM Model

- So, we have:
  - Missions
  - Boat types
  - Capabilities of each boat type for different missions

Missions (M)	
$m \in M$	Name
1	SAR
2	PWCS
3	LMR
4	CD
5	AMIO
6	ELT
7	RBS
8	Marine Safety
9	MEP
10	ATON
11	Training
12	Cmd Flexibility/Discretion

Boat Types (T)	
$t \in T$	Name
1	MLB
2	SPC-NLB
3	SPC-HWX
4	RB-M
5	RB-S
6	RBS-AUX
7	SPC-LE
8	SPC-SW
9	SPC-AIR
10	SPC-ICE
11	SPC-SKF

Capabilities (C)		
$c \in C$	Name	$\{t \in T \mid G_{tc} = 1\}$
1	AUXOPS	$\{5, 6\}$
2	FLOOD	$\{11\}$
3	HWX	$\{1, 2, 3, 4\}$
4	LH-ICE	$\{9\}$
5	PURSUIT	$\{4, 7\}$
6	SH-ICE	$\{10\}$
7	SHALLOW	$\{2, 8, 11\}$
8	SURF	$\{1, 2, 3\}$
9	TACTICAL	$\{1, 4, 5, 6, 7\}$
10	TRAILER	$\{5, 6, 8, 11\}$
11	BIG	$\{1, 2, 3, 4\}$

Boat Allocation Module Project

- Overall Project Goal:
  - Design and implement a software package:
    - To be used solely and independently by USCG analysts
    - To serve as a decision-making tool when faced with questions related to re-allocation of boats among USCG stations
- Project sought to create a mathematical model that could produce “good assignments” of boats to boat stations so all station requirements are met.

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Boat Allocation Module Project

- What Makes One Boat Allocation Better than Another?
  - ➢ ***Minimize Budget***: Total cost (of hourly use, personnel training, routine maintenance) is as small as possible, while still allowing all tasks to be completed
  - ➢ ***Minimize "Unmet Hours"***: Include limiting budget as a constraint and try to minimize the "unmet" task demand.
- ➢ We formalized both ideas, but our tool is designed around the latter. It can, however, be used to do "what if" experiments to address the former.

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BAM: Technical Model

- ***Operations Research*** optimization problem
- ***Mixed Integer Programming***
- What we do not do:
  - No focus on individual boats; rather on total number of boats at a station
  - Don't consider assignment of personnel to stations or boats – up to the Commanding Officer after boats assigned to stations and mission hours to boats

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BAM: Technical Model

- ***UnMet Hours***: Minimize the deviation under the desired number of hours for each mission at each boat station
- ***Precise formulation of the objective function and the constraints was a long-term collaborative effort.***
- It required:
  - Back and forth with experts on boat allocation
  - Computer experimentation with different versions to make sure constraints were formulated as we intended them to be.

BAM: Technical Model

- The problem can be modeled as a variant of the well-studied "***Resource Allocation Problem***"
- Widely studied optimization problem.
- Known to be computationally "hard" in theory
- Moderately-sized applications can typically be solved close to optimality in a reasonable amount of time.
- ***Our solution employs a powerful heuristic technique: Branch and Bound***
- We encode our problem in a leading commercial optimization package, ***Xpress-MP***.
- This includes a "state of the art" Branch and Bound method.

BAM: Technical Model

- Model was subjected to extensive and precise testing at all stages of development
- Our software has been tested on USCG computers by USCG users
- Our software has been delivered to the Coast Guard along with a detailed User Guide

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BAM Model (Unmet Hours)

$$
\begin{aligned}
\text{minimize} \quad & \sum_{s\in S}\sum_{m\in M} W_{sm}x_{sm} + \alpha\sum_{t\in T} u_t + \beta\sum_{s\in S} v_s && && (1)\\
\text{subject to} \quad & \sum_{t\in T} G_{tc}b_{ts} \geq R_{sc} && \forall c\in C, s\in S && (2)\\
& \sum_{t\in T} G_{tc}y_{ts} \leq R'_{sc} && \forall c\in C, s\in S && (3)\\
& \sum_{s\in S} b_{ts} \leq B_t + u_t && \forall t\in T && (4)\\
& \sum_{t\in T} b_{ts} \leq P_s + v_s && \forall s\in S && (5)\\
& b_{ts} \leq B'_t y_{ts} && \forall t\in T, s\in S && (6)\\
& \gamma\cdot y_{ts} \leq b_{ts} && \forall t\in T, s\in S && (7)\\
& h_{tsm} = 0 && \forall t\in T, s\in S, m\in M : \lambda_{tm} = 1 && (8)\\
& \sum_{m\in M} h_{tsm} \geq A'_t b_{ts} && \forall t\in T, s\in S && (9)\\
& \sum_{m\in M} h_{tsm} \leq (A_t + E_t)b_{ts} && \forall t\in T, s\in S && (10)\\
& \sum_{s\in S}\sum_{m\in M} h_{tsm} \leq (A_t + L_tE_t)\sum_{s\in S} b_{ts} && \forall t\in T && (11)\\
& h_{t,s,11} \geq U_t y_{ts} && \forall t\in T, s\in S && (12)
\end{aligned}
$$

BAM Model (Unmet Hours)

$$\sum_{s\in S}\left(\sum_{t\in T}(F_t b_{ts} + V_t \sum_{m\in M} h_{tsm}) + \sum_{i\in I} J_i z_{si}\right) \leq D \tag{13}$$

$$z_{si} \geq \sum_{t\in T} y_{ts} - i \qquad \forall s \in S, i \in I \tag{14}$$

$$z_{si} \geq 0 \qquad \forall s \in S, i \in I \tag{15}$$

$$x_{sm} \geq H_{sm} - \sum_{t\in T} h_{tsm} \qquad \forall s \in S, m \in M \tag{16}$$

$$x_{sm} \geq 0 \qquad \forall s \in S, m \in M \tag{17}$$

$$q_{tk} = \sum_{s\in S} Q_{sk} b_{ts} \qquad \forall t \in T, k \in K \tag{18}$$

$$q_{tk} \in \{0, 1, 2, \ldots\} \qquad \forall t \in T, k \in K \tag{19}$$

$$y_{ts} \in \{0, 1\} \qquad \forall t \in T, s \in S \tag{20}$$

$$u_t \in \{0, 1, 2, \ldots\} \qquad \forall t \in T \tag{21}$$

$$v_s \in \{0, 1, 2, \ldots\} \qquad \forall s \in S \tag{22}$$

$$h_{tsm} \geq 0 \qquad \forall t \in T, s \in S, m \in M \tag{23}$$

$$b_{ts} \geq 0 \qquad \forall t \in T, s \in S \tag{24}$$

BAM Model – Input Parameters

Input Parameters		
Type	Notation	Description
	C	Set of capabilities
	I	Index set $\{1, 2, \ldots, \lvert T\rvert - 1\}$
Set	M	Set of missions
	T	Set of boat types
	Dis	Set of districts
	Sec	Set of sectors
	S	Set of stations
	K	Set of nil, districts, sectors or individual stations ($K \in \{\emptyset, Dis, Sec, S\}$)

BAM Model – Input Parameters

Array	α	Penalty term per assigned boat of type $t \in T$ exceeding inventory (B_t)
	β	Penalty term per assigned boat exceeding capacity at station $s \in S$
	A_t	Preferred number of hours to be spent on any assigned boat of type $t \in T$
	A'_t	Minimum number of hours to be spent on any assigned boat of type $t \in T$
	B_t	Maximum number of boats of type $t \in T$ available to be assigned
	B'_t	Maximum number of boats of type $t \in T$ allowed at a station
	D	Total budget in U.S. Dollars
	E_t	Maximum number of extra hours allowed for each boat of type $t \in T$
	F_t	Cost of assigning a single boat of type $t \in T$ to a station
	γ	A fraction in $[0, 1]$, denoting the minimum a fractional boat assigment value can take (*i.e.* b_{ts} is either zero-valued or "not too close" to zero when it is positive)
	G_{tc}	Binary entry denoting if a boat of type $t \in T$ is within capability $c \in C$
	H_{sm}	Preferred number of hours to be spent on missions of type $m \in M$ at $s \in S$
	J_i	Incremental cost of having $i + 1$ boat types assigned, $i \in I$
	λ_{tm}	Binary entry denoting whether a boat of type $t \in T$ is forbidden to perform missions of type $m \in M$ (1) or not (0)
	L_t	Maximum fraction of total extra hours for all boats of type $t \in T$
	P_s	Maximum number of boats allowed at station $s \in S$
	Q_{sk}	Binary value denoting if a station $s \in S$ belongs to unit $k \in K$ (1) or not (0)
	R_{sc}	Minimum number of boats required from the subset of boat types with capability $c \in C$, at stations $s \in S$
	R'_{sc}	Maximum number of boat types allowed at station $s \in S$ to satisfy $c \in C$
	U_t	Minimum number of training hours a station requires when at least one boat of type $t \in T$ is assigned
	V_t	Cost per hour of using a single boat of type $t \in T$
	W_{sm}	Weight of importance assigned to missions of type $m \in M$ at station $s \in S$

BAM Model – Decision Variables

Decision Variables		
Binary	y_{ts}	A value of 1 corresponds to assigning at least one boat of type $t \in T$ to station $s \in S$, 0 otherwise
Integer	q_{tk}	A non-negative integer denotes the number of boats of type $t \in T$ assigned to each unit $k \in K$
	u_t	A non-negative integer denotes how many extra boats of type $t \in T$ are needed in order to ensure feasibility of our problem
	v_s	A non-negative integer denotes how many extra boats of any type are needed at station $s \in S$ in order to ensure feasibility
Continuous	b_{ts}	A non-negative value denotes the (fractional) number of boats of type $t \in T$ assigned to station $s \in S$
	h_{tsm}	A non-negative value denotes the (fractional) number of hours assigned to all boats of type $t \in T$ at station $s \in S$ for missions of type $m \in M$
	z_{si}	A non-negative value denotes the total number of boat types above $i \in I$, at station $s \in S$
	x_{sm}	A non-negative value denotes the total number of hours under the preferred H_{sm} for $s \in S$, $m \in M$

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BAM Model (Unmet Hours) Constraint Explanations

(1) is our objective function, which asks to minimize the total number of hours under the maximum a station $s \in S$ has spent on missions of type $m \in M$, which is typically written as:

$$\text{minimize} \quad \sum_{s \in S} \sum_{m \in M} W_{sm} \left(H_{sm} - \sum_{t \in T} h_{tsm} \right)^{+},$$

once the smallest increase in total inventory ($\sum_t u_t$) as well as total pier space ($\sum_s v_s$) have been found (assuming α and β are large enough, *e.g.* 1,000,000);

(2) guarantees that the minimum number of boats (R_{sc}) is selected from over the feasible set $\{t \in T | G_{tc} = 1\}$ which in turn satisfies the capability requirement of $c \in C$, for each station $s \in S$ (NOTE: we only need to include such constraints when $R_{sc} > 0$ since our variables and parameters are nonnegative);

(3) guarantees that the maximum number of boat types satisfying the capability requirements (R_{sc}), is not more than that allowed (R'_{sc}) (NOTE: if there is no restriction or $\sum_t G_{tc} \leq R'_{sc}$, then we do not encode such a constraint, and signify as such $R'_{sc} := 0$);

(4) guarantees that we do not schedule more than the total number of boats (B_t) of type $t \in T$ available to all stations if possible, else u_t will give us a positive number denoting the minimum increase B_t needs for a feasible assignment to exist;

(5) guarantees that we do not assign more boats in total ($\sum_{t \in T} b_{ts}$) than the maximum number allowed at station $s \in S$ (P_s), else v_s will give a positive number denoting the minimum increase P_s needs for a feasible assignment to exist;

(6) guarantees that the number of boats of type $t \in T$ at station $s \in S$ (b_{ts}) is not more than that allowed at any station (B'_t, which is equal to B_t if no restriction is to be imposed), and $b_{ts} = 0$ if $y_{ts} = 0$;

BAM Model (Unmet Hours) Constraint Explanations

(7) guarantees that we do not assign a fraction of boats (b_{ts}) less than γ percent to any station, and $y_{ts} = 0$ if $b_{ts} = 0$;

(8) guarantees that if a boat type $t \in T$ cannot satisfy a mission of type $m \in M$, then it is not assigned any hours ($h_{tsm} = 0$), for every station $s \in S$ (NOTE: this can be encoded as a single constraint $\sum_{t,s,m} \lambda_{tm} h_{tsm}$, since $h_{tsm} \geq 0$ and $\lambda_{tm} \geq 0$);

(9) guarantees that each boat of type $t \in T$ assigned to a station $s \in S$ is given a minimum number of total hours A'_t;

(10) guarantees that the total number of hours spent on any mission on boats of type $t \in T$ at station $s \in S$ ($\sum_{m \in M} h_{tsm}$) is at most the total number of preferred hours for all boats of this type ($A_t b_{ts}$) plus the amount of overtime allowed on such boats ($E_t b_{ts}$), otherwise $\sum_m h_{tsm} = 0$ (implying $h_{tsm} = 0$ for each $m \in M$) whenever b_{ts};

(11) guarantees that the total number of hours spent on all boats of type $t \in T$ (over all missions and all stations, $\sum_{s \in S} \sum_{m \in M} h_{tsm}$) is at most the total number of hours preferred for all assigned boats of this type ($A_t \sum_{s \in S} b_{ts}$) plus some fraction of the available amount of overtime ($L_t E_t \sum_{s \in S} b_{ts}$);

(12) guarantees that if a boat of type $t \in T$ is assigned to station $s \in S$, then that station requires at least U_t hours of training;

(13) guarantees that the total cost of assigned boats ($\sum_{s \in S} \sum_{t \in T} F_t b_{ts}$), plus the total cost of assigning hours to each boat in use ($\sum_{s \in S} \sum_{t \in T} V_t h_{ts}$), plus the cost of having excess distinct boat types assigned ($\sum_{i \in I} C_i z_{si}$), does no exceed the budget (D);

BAM Model (Unmet Hours) Constraint Explanations

(14) and (15) linearly encode the terms $z_{si} = \max\{\sum_{t\in T} y_{ts} - i, 0\}$ (also written as $(\sum_{t\in T} y_{ts} - i)^+$), which penalize incrementally any solution using $i+1$ distinct boat types;

(16) and (17) linearly encode the terms $x_{sm} = (H_{sm} - \sum_{t\in T} h_{tsm})^+$, which appear in our objective function as the number of "unmet hours";

(18) and (19) guarantee that although a fractional number of boats of type $t \in T$ may be allowed at any single station $s \in S$ (b_{ts}, when $K = S$), we still have an integral number assigned to each unit $k \in K$ ($\sum_{s\in S} Q_{sk} b_{ts}$) (NOTE: if $K = S$, then $q_{tk} = b_{ts}$ with $k = s$, so we can drop the variables q and just let b be integral; and we let $K =$ denote that we at least want a whole number of boats assigned to the entire instance of stations);

(20) guarantees that our decision variable y_{ts} is binary;

(21) and (22) guarantee that our variables are integral (NOTE: each u_t will be integral since $\sum_s b_{ts} = \sum_{s,k} Q_{tk} b_{ts}$ is integral, and v_s will be integral if $K = S$, so we may encode by relaxing the integrality of such variables to non-negativity);

(23) and (24) guarantee that our variables will never be negative-valued;

Using our Tool

- Tool can give you allocation of boats to stations given inputs such as:
  - Total budget
  - Requested hours per mission at each station
  - Number hours a particular kind of boat can be used before maintenance
  - Maximum number of boats of a given type allowed at a station
  - Weight of importance assigned to missions of a given type at a given station

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Using our Tool

- Tool can be used to do “what if” tests:
  - If we cut the budget by 5%, how can we change some of the requirements to make the new budget achievable without unmet mission hours?
    - Is across the board 5% cut in mission hours required the way to go?
    - Should we cut mission hours for certain missions?
    - Can we loosen requirements on hours before maintenance?
    - Can we loosen restriction on number of boats at a given station?

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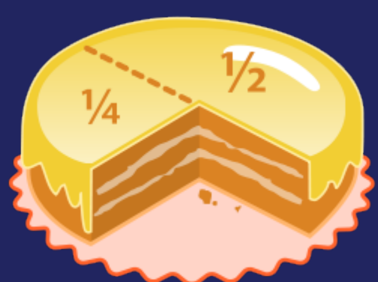
A Key Observation

- Our tools are estimated to save the Coast Guard $120 million over a period of 20 years.
- Our first formulation of the problem was as an integer programming problem.
- ***But: we observed that if we allow fractional solutions, the solutions are more efficient (cheaper) and faster***.
- But what does a fractional solution mean?



Credit: en.wikipedia.org

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A Key Observation

- Fractional solution corresponds to ***sharing boats*** between boat stations.
- ***This goes completely against "the culture" of the Coast Guard.***
- They have never done it and at first it made them very uncomfortable

Credit: Wikiipedia.org

A Key Observation

- Admiral Daniel Abel: “When was the last time you rented a car and washed and waxed it before returning it?”

Credit: groupon.com

FR and Admiral Daniel Abel, Coast Guard District 1

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Advantages of Sharing

- What does sharing get you?
- Small example: three stations, 300 boat hours required per station per quarter, maximum hours per boat per year = 1000

	Qtr 1	Qtr 2	Qtr 3	Qtr 4
Station 1	300	300	300	300
Station 2	300	300	300	300
Station 3	300	300	300	300

- Conclusion: ***If no sharing, need two boats per station, or 6 boats in all.***

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Advantages of Sharing

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- Small example: three stations, 300 boat hours required per station per quarter, maximum hours per boat per year = 1000

	Qtr 1	Qtr 2	Qtr 3	Qtr 4
Station 1	300 Boat 1	300 Boat 2	300 Boat 2	300 Boat 2
Station 2	300 Boat 3	300 Boat 1	300 Boat 3	300 Boat 3
Station 3	300 Boat 4	300 Boat 4	300 Boat 1	300 Boat 4

- Conclusion: ***This solution shows you can get away with 4 boats if you allow sharing of Boat 1.***

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Advantages of Sharing

	Qtr 1	Qtr 2	Qtr 3	Qtr 4
Station 1	300 Boat 1	300 Boat 2	300 Boat 2	300 Boat 2
Station 2	300 Boat 3	300 Boat 1	300 Boat 3	300 Boat 3
Station 3	300 Boat 4	300 Boat 4	300 Boat 1	300 Boat 4

- Conclusion: This solution shows you can get away with 4 boats if you allow sharing of Boat 1.
- What if you only allow a boat to be moved once a year? Is there a solution with 4 boats?
- What if a boat can only be shared between 2 stations?
- What if a boat can't be idle for a full period?

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A Key Observation

- We presented the results to Admiral Mark Butt at Coast Guard HQ in Washington, DC.
- With the help of our Coast Guard research partners, we convinced the Coast Guard leadership that boat sharing was worth exploring.
- The Coast Guard is now working with us on a practical implementation of boat sharing. ***The culture is changing***.

Delivering Report on Boat Allocation Module to Admiral Butt

Future Work: Phase II: BAM

- Boat Sharing Phase II initial approach:
  - Think about restrictions:
    - Geographic
    - Costs
    - Frequency of boat switches
    - Limit number of stations sharing a boat
  - Part A: Boats can be allocated to stations with variety of time frames allowed for switching
  - Simulate this to determine potential savings with sharing
  - Part B: model that only allows switching boat between stations a limited number of times

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Future Work: Phase II: Aviation

- Next steps for the project: Aviation Problem posed by Coast Guard
  - Similar problem for Coast Guard aircraft
  - Complication: aircraft heavily used for search and rescue operations, but these are distributed over space and time
  - Complication: aircraft break down and breakdowns are distributed over time in a stochastic way

Keys to Successful Project and of Path to Transition

- Early and continual communication with Partner Agency (USCG)
- High Level commitments within Agency
- Effective technical POCs within Agency
- Easy email/telephone to resolve small issues
- Willingness to educate us about complex missions
- As required: meetings onsite and longer-term embeddings of USCG personnel
- Ongoing transmission of technical results
- Ongoing Verification, Validation & Authentication (VVA)
- Effective documentation for transition

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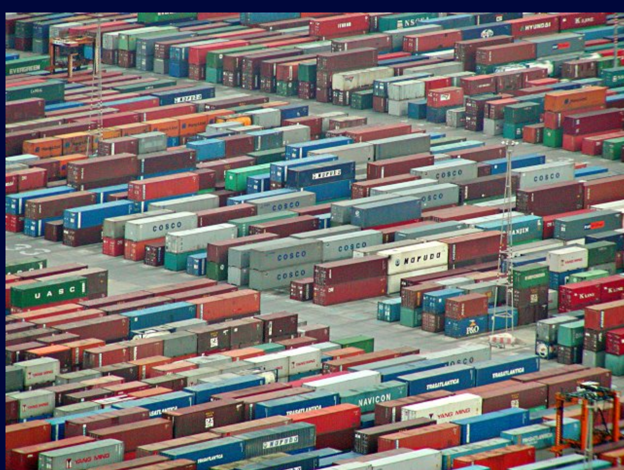
Keys to Successful Project

- Strengths of the USCG team we worked with
  - Value of having team members with Masters degrees in Operations Research combined with real operational experience.
  - Leadership of the modeling team and hands-on involvement by team and its leadership
  - Unique ability of Coast Guard team to understand both the real world applications and the math behind the modeling – and to interact well with the academic researchers.
  - Technical skills of Coast Guard team led them to understand the sharing concept and advocate for it with Coast Guard leadership.

Example II: Container Inspection at Ports



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Container Inspection at Ports

- A large and expensive job
- Critical that it be carried out effectively and efficiently.
- 95% of goods coming into the US come on ships
- In the 21st century, the marine transportation system has become a complex, just-in-time operation.
- Keeping ports operational and moving cargo is of central importance to the world economy and in keeping the supply chain moving.

Data Credit: Forbes Business 10/25/11; Wikipedia

Port of New York/New Jersey

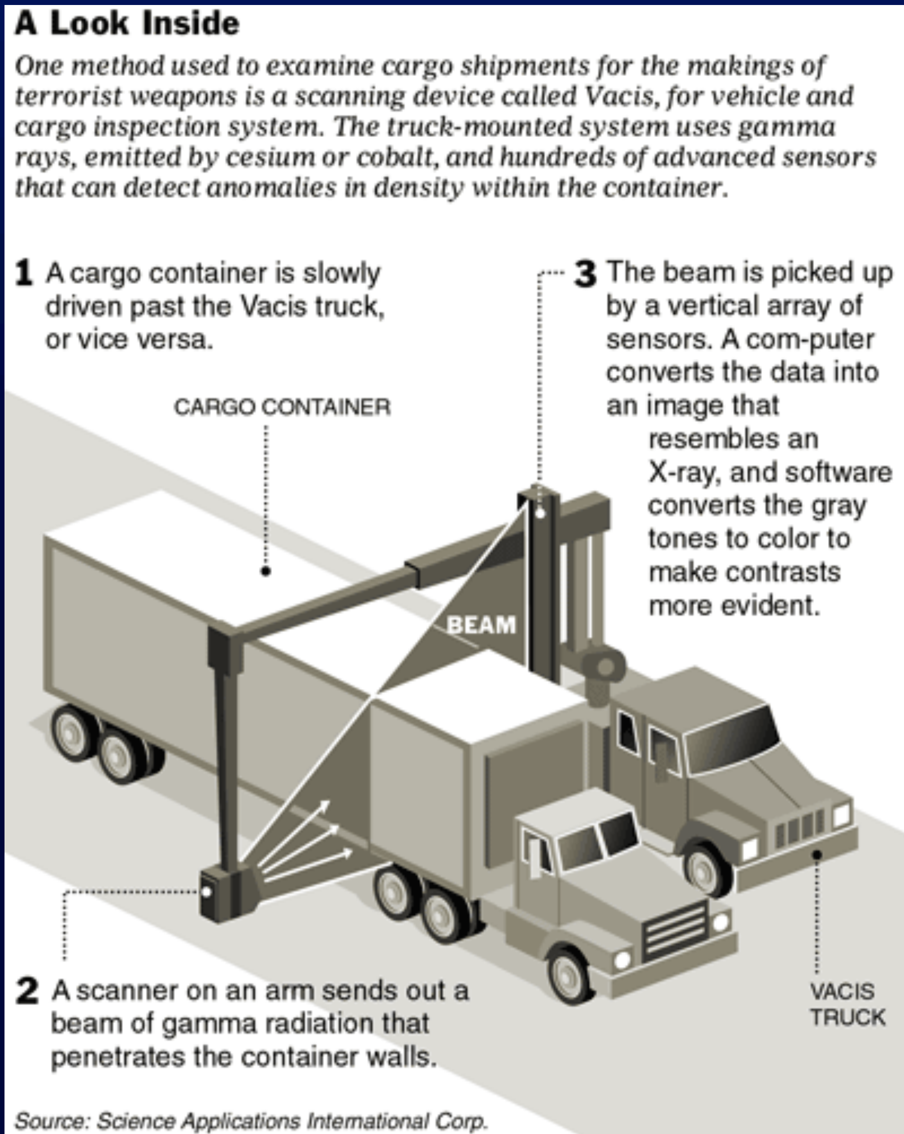
- Third largest port in USand largest on the East Coast
- 23rd busiest port in the world (based on cargo volume)
- Supports the most densely populated area in North America
- 32.2 metric tons of cargo per year
- 5,292,000 containers per year
- 700,000 cars per year
- A critical element of the regional economy

Data Credit: Forbes Business 10/25/11; Wikpedia

Container Inspection at Ports

- US Customs and Border Protection (CBP) is responsible for inspection at ports and borders.
- At container ports, we use VACIS machines
- VACIS = Vehicle and Cargo Inspection System

Image Anomaly - VACIS



VACIS Inspection Processes at APM Terminal

- Project Goal: study the VACIS operation at the APM terminal in Port Elizabeth, NJ using ***simulation modeling and analysis to improve VACIS operational efficiency and throughput.***
- A simulation model was built to capture
  - vessel arrivals
  - container storage at the yard
  - presentation of containers to CBP officers
  - and the actual inspection processes.

- A number of scenarios were analyzed to understand the capabilities of the inspection process under various surge conditions

Performance Metrics

- The simulation model produces statistical results for the inspection performance metrics as well as the port performance metrics.
- **Inspection statistics** metrics:
  - Inspection processing time per container
  - # containers inspected in 48 hours in a designated batch
  - % containers inspected in 48 hours in a designated batch
  - Time to complete a batch of designated quantity
- **Port statistics** metrics:
  - Port time per inspected container (from vessel arrival to inspection completion)
  - Time elapsed from vessel arrival to segregation area
  - Time spent in segregation area
  - Delay in inspection area
  - Inspection time

Performance Metrics

- ***Impact*: *A revision was proposed in the way the hourly throughput is calculated in CBP's inspection operations to better reflect CBP operational metrics.***
  - ***Overall throughput per hour*:** Hourly throughput based on the total time spent at the terminal.
  - ***Effective throughput per hour*:** Hourly throughput based on the actual hours worked.

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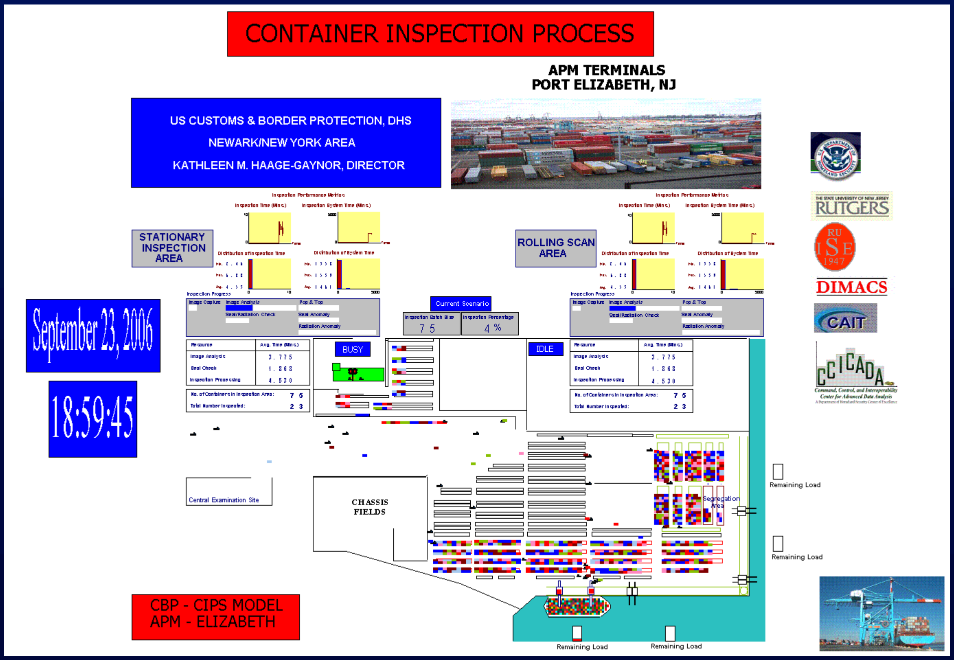
The Simulation Model

Use Discrete Event Simulation with ARENA software

The animation displays:

- The incoming workload with ship arrivals and departures
- Loading and unloading of containers by cranes
- Shuttling of containers to storage areas
- Transfer of CBP-specified containers to the inspection area
- Container inspection processes
  - Stationary Scan
  - Moving Scan



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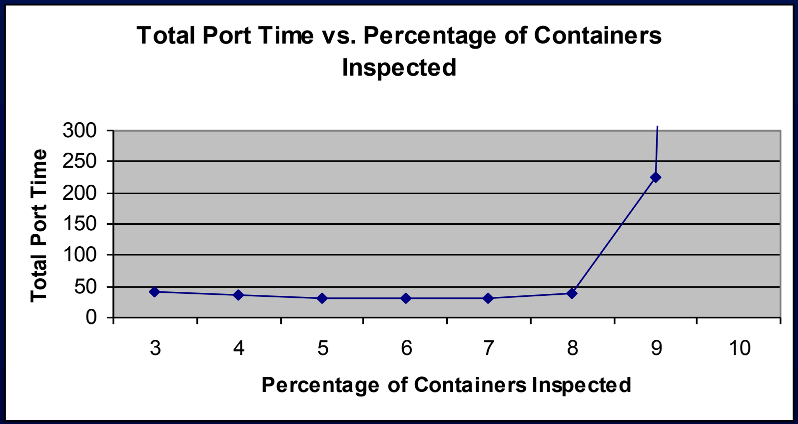
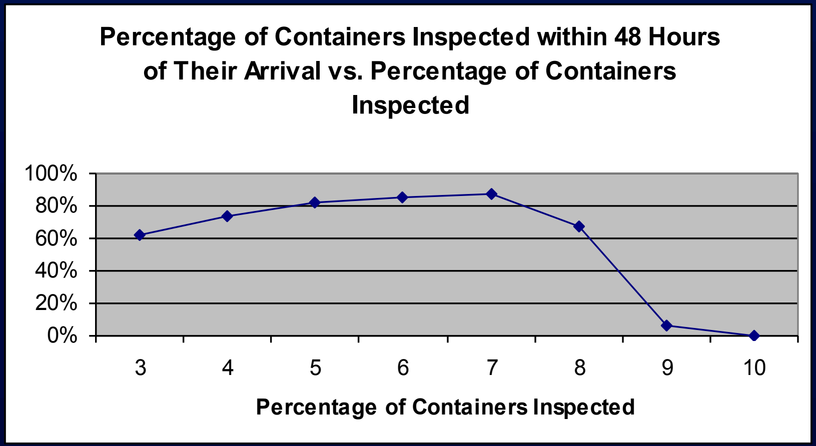
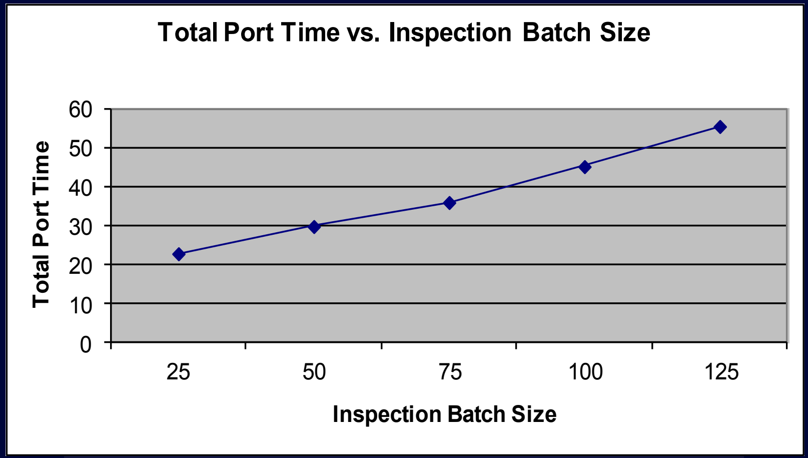
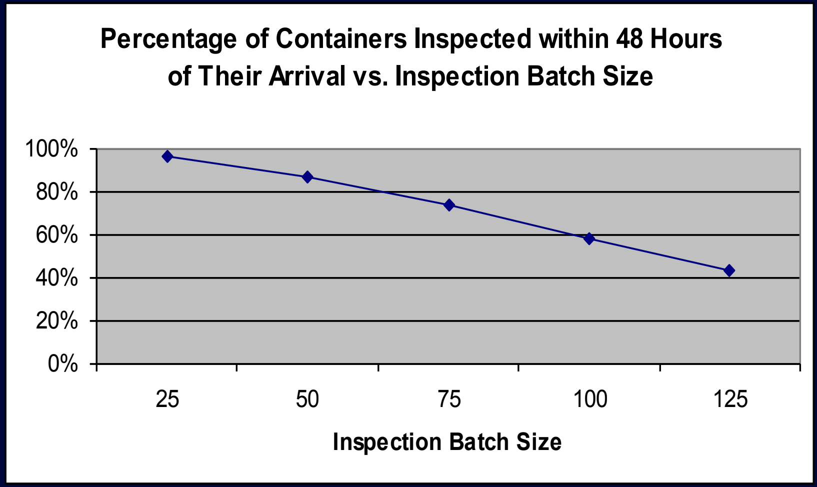
Results of Simulations

For a fixed inspection batch size what is total time from container arrival to inspection completion? What % of containers can be inspected within 48 hrs of arrival?









Container Inspection at Ports

- Right now, we bring the inspectors to the ports.
- There is often a delay in waiting for an inspector to come to a port to inspect the containers that are lined up waiting there.
- The modeling work that we and others did led CBP to ask: ***Is it better to bring the inspectors to the containers or to bring the containers to the inspectors?***
- This would require a ***change in the culture***.
- It is not what we are used to doing
- There is a lot of skepticism about it.


Damian Dovarganes / AP file

Container Inspection at Ports

- CBP decided to try something different: Set up warehouses away from the ports, keep inspectors there, and bring containers to the warehouses to have them inspected.
- A ***"change in the culture"***
- CBP of New York/Newark approached CCICADA to help with new initiative.
- CBP is experimenting with the new approaches
- Questions: Does this make inspection more efficient (faster throughput)? Does it make them less costly?
- CCICADA project: modeling and analysis of new approaches

Port NY/NJ Container Terminals

- **Global Marine Terminal**
  302 Port Jersey Blvd.,
  Jersey City, NJ 07305
- **Port Newark Container Terminal (PNCT)**
  241 Calcutta St.,
  Port Newark, NJ 07114
- **Maher Terminal**
  1210 Corbin St.,
  Elizabeth, NJ 07201
- **APM Terminals (Maersk)**
  5080 McLester St.,
  Elizabeth, NJ 07207
- **New York Container Terminal**
  300 Western Ave.,
  Staten Island, NY 10303
- **Red Hook Container Terminal**
  70 Hamilton Ave.,
  Brooklyn, NY 11231

Container Inspection Off-site

- *Phase 1*: Establish set of baseline measures for current operating procedures; identify key variables needed for simulation modeling
- *Phase 2*: simulation modeling of operation of offsite facilities; evaluate performance using objective functions developed together with CBP; produce software tool customs planning personnel can use

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Container Inspection Off-site

- Project aimed to help evaluate and identify benefits for CBP in moving forward with this new initiative
- ***Initiative has major national implications for way we inspect containers at ports***
- *Phase 3*: Develop templates that can be used in ports all across the US; develop software tool that can be used by customs planning personnel at all inspection sites

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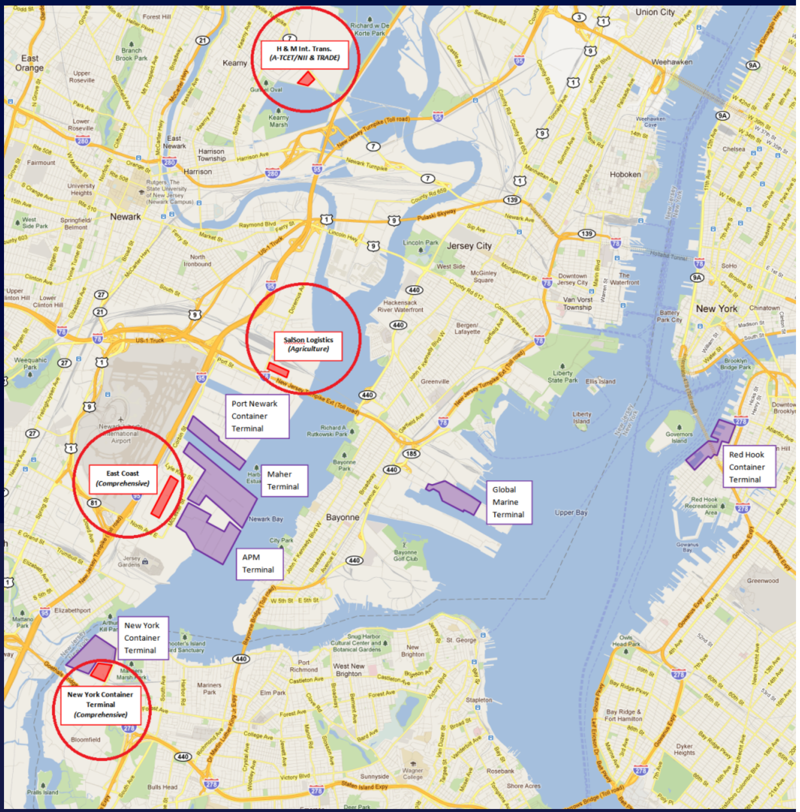
2012 CBP Inspections Re-structuring

- The inspection process has moved **off-site** and now occurs in privately owned central examination stations (**CESs**).
- The containers are now being carried to these facilities by trucks.
- The four CES facilities operating in 2012:
- Comprehensive CESs
  - **East Coast Warehouse**, 1130-1150 Polaris Street, Port Elizabeth, NJ
  - **New York Container Terminal**, 241 Western Avenue, Staten Island, NY
- A-TCET/NII and Trade CESs
  - **H&M International Transportation**, 700 Belleville Turnpike, Kearny, NJ
- Agriculture CES
  - **SalSon Logistics Inc,** 888 Doremus Avenue, Newark, NJ



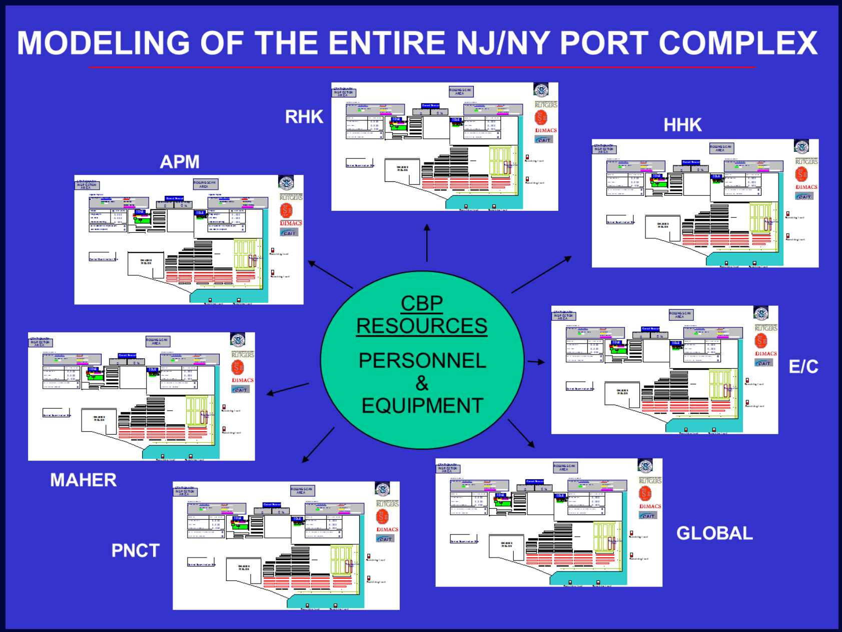
CBP Examination Processes 2010, 2011 & 2012 Performance Comparisons

- CCICADA has ***examined and compared 2012 inspection cycle times with those of prior years and before off-site inspection.***
- A breakdown of container cycle times (from arrival of container until CBP release) has been obtained for each inspection process.
  - CET VACIS (NII) inspection
  - CET Back-in inspections
  - Agriculture Back-in inspections
  - Agriculture Back-in Cold Treatment inspections
  - Agriculture Full-strip inspections
- CES (inspection facility) performances were compared for 2012

Modeling and Simulation

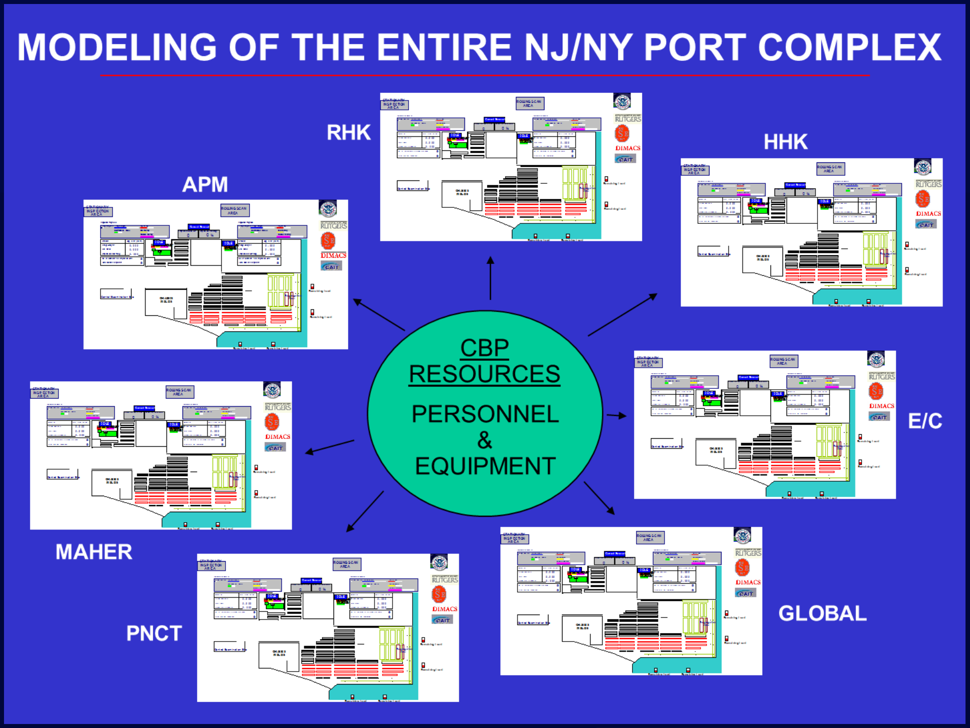
- By gathering detailed information about the operational and business processes at the CES facilities, it is ***possible to develop a model of the new off-site inspection process*** similar to the one previously developed for CBP.

- The model will ***help to review alternative modifications*** to inspection procedures and offsite-inspection-facility operations.



Modeling and Simulation

- As a result, it will be possible to suggest modifications that will ***optimize performance based on key metrics*** such as throughput or employee work time.



- It will also be ***helpful to evaluate alternative changes in procedures*** that might be potentially beneficial, especially to enhance port security and to minimize costs to CBP and to the port/ trade community.

Change in the Culture

- CBP seems committed to continuing the experiment with offsite inspections at warehouses.
- There does apparently seem to be a "***change in the culture***"

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Future Work – Security Implications

- One of the challenges any container inspection process faces is its ***robustness*** under security disruptions.
- An analysis can be performed to ***understand the impact of a disruption in operations.***
- Several disruption scenarios can be developed leading to an accumulation of containers at the terminals.
- Alternative procedures/algorithms for dispatching the containers to operating CESs can be considered, with a goal of sharing the workload among available CESs and minimizing delays.

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Example III: Inspections at Sports Stadiums & Large Gathering Places

- Earlier work: modeling and simulation of sports stadium evacuation led us to close collaborations with National Football League (NFL) security and stadium operators.
    - Worked with 6 NFL stadiums and Indianapolis SuperBowl
    - Work applied during lightning storm at MetLife Stadium in NJ

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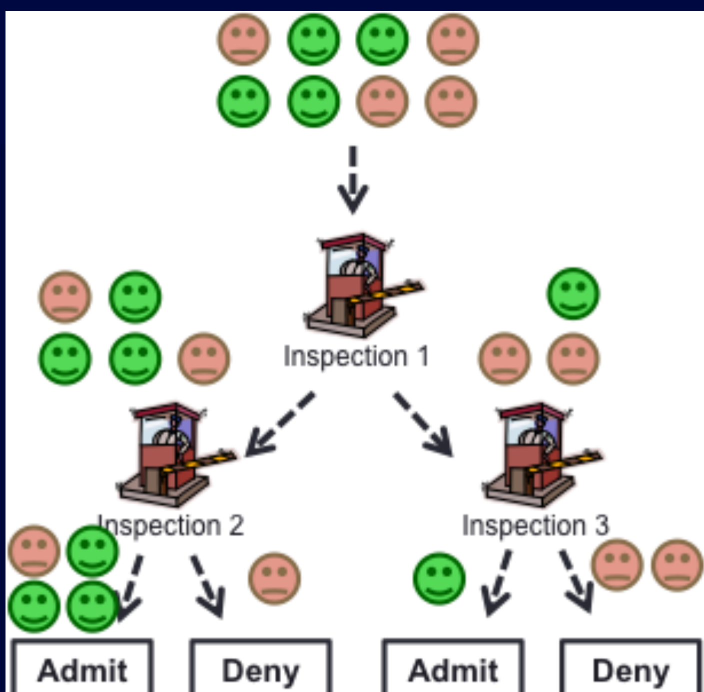
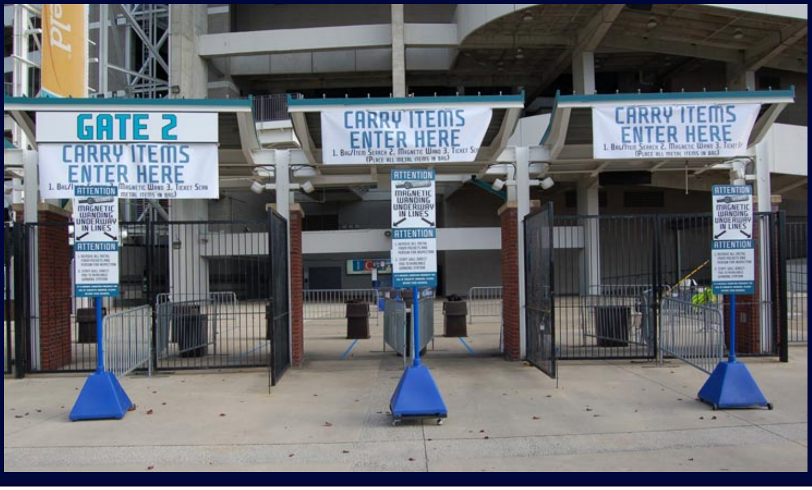
Security at NFL Stadiums

- Working with NFL stadiums
- Looking at variety of inspection problems
- Gathering data about how they do layered defense and building simulation models



Stadium Security

- We work with all major sports leagues (NFL, National Basketball Assn (NBA), National Hockey League (NHL), Major League Baseball, Major League Soccer, US Lawn Tennis Assn, NASCAR auto racing) + college football & basketball + minor league baseball & hockey, etc.



Security Project Goals

Improve: Effectiveness, Efficiency & Satisfaction

- Maintain and improve the ***effectiveness*** of patron inspection procedures and processes: identify *contraband* items
- Improve **efficiency**: reduce resource costs (financial, time, staffing, etc.) associated with the procedures/processes; and
- Maintain and improve patron ***satisfaction*** as enhanced procedures are applied to individuals attending stadium events.

Security at NFL Stadiums

- In practice: Started by looking at three types of inspection:
  - ***Wanding***
  - ***Pat-down***
  - ***Bag inspection***

- Observed stadium inspections and gathered data about each type of inspection, in particular length of time it takes.
- Data shows major differences depending on inspector, time before game start, etc.

Stadium Inspection

- NFL asked all stadium security operators to perform 100% wanding of patrons.
- This didn't always work. Close to game start time, lines got too long.
- Met with NFL Security
- Began analysis of security procedures at one stadium

Approach

- Data Collection, Examination, and Analysis of:
  - Efficiency (inspection times) and Effectiveness (detection of contraband).
  - Comparison of pat-down, wanding, and bag check
  - Anonymous comparison of different inspectors
  - Comparison of different gates
  - Physical design of pods
  - Ticket scanning process and related data
  - Arrival patterns of patrons over time

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Data Analysis - SUMMARY

- We evaluated the ***effect of several important factors on the inspection times***:
  - **Inspection method** (pat-down, wanding, or bag check)
  - **Location** (gate, pod, lane ~ inspector)
  - **Time before event** (early wave vs. late wave)
    - Early wave = from time of gate opening until waiting line is cleared
    - Late wave = from time of crowd accumulation until event start
  - **Type of event/crowd demographics** (soccer match, monster truck)

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Data Analysis

- Since there is a lot of (random) variation, we analyzed the results using statistical methods.

CONCLUSIONS

- Inspection time distributions differ significantly according to
  - Inspection methods
  - Times
  - Inspectors
  - Gates
  - Events
- *Statistical analysis shows that the differences are much greater than can be explained by random chance.*

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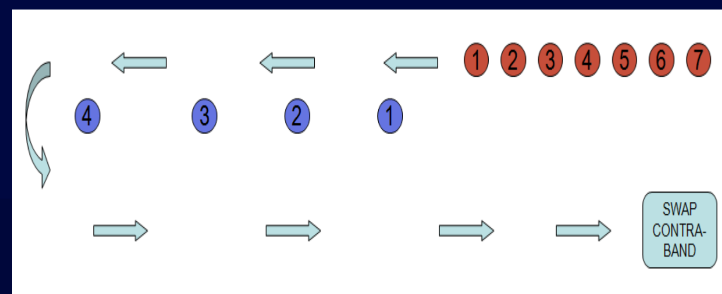
Data Analysis: Training

- We designed protocol for evaluating effectiveness of training wanders at a stadium
- We observed training of wanders
- Findings reported to NFL Security



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Data Analysis

- Stadium security observed that 100% wanding didn't work: lines got too long as game time approached.
- They stopped wanding when lines got too long and did less thorough inspection: "pat down"

Credit kitv.com

Boston, April 15, 2013

How does that change things?

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Boston April 15, 2013

Credit people.com

How does that change things?

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Boston, April 15, 2013

C
Credit
consortiumnews.com

The day after the Boston attack, we met with security at an NFL stadium.
The next day, we met with NFL Security in NYC

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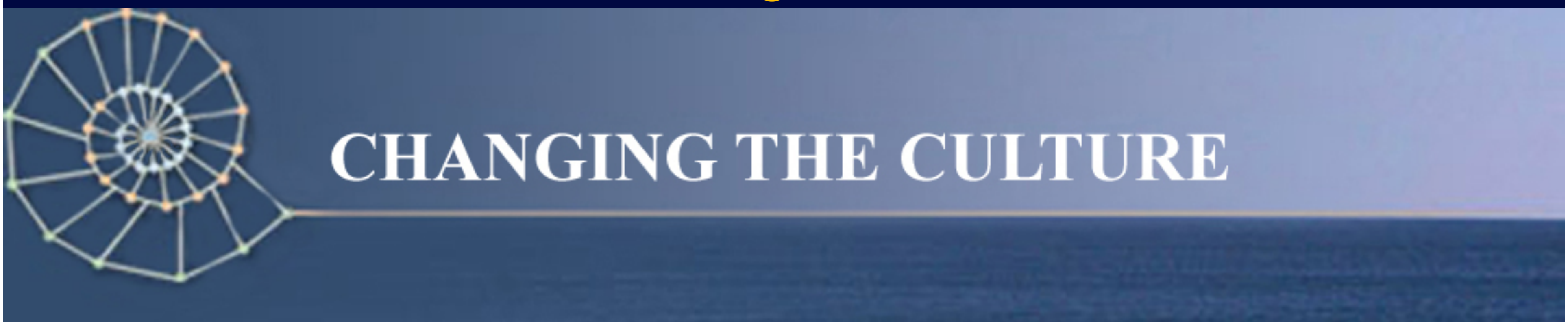
Data Analysis

- After Boston, National Football League decided it needed to be more strict about inspections.
- If you are going to wand all patrons, how do you get them into the stadium in time?
- Potential solution: ***"change the culture"***



Credit: uri.edu

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Data Analysis

- NBA uses walk through magnetometers, as in airports
- NFL experimented with use of walk-through magnetometers.

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Data Analysis

- We are in the process of analyzing the strategy of going to 100% magnetometer use
- Issues:
  - ***Project*** number of magnetometers needed to deal with largest expected throughput challenges
  - Observe time required for throughput
  - Model physical location
  - Consider effect of weather on performance

Data Analysis

- Problem – also can't get people in by game time.

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Simulation as a Planning Tool

- **Simulation modeling – strategic planning:**
  - Based on the information obtained from the data collected during in-person observation and video analysis, we have developed a ***simulation*** of entrance queues.
  - Using the data from actual distributions, we have used the simulation to evaluate the speed and cost of inspection for various alternative policies.

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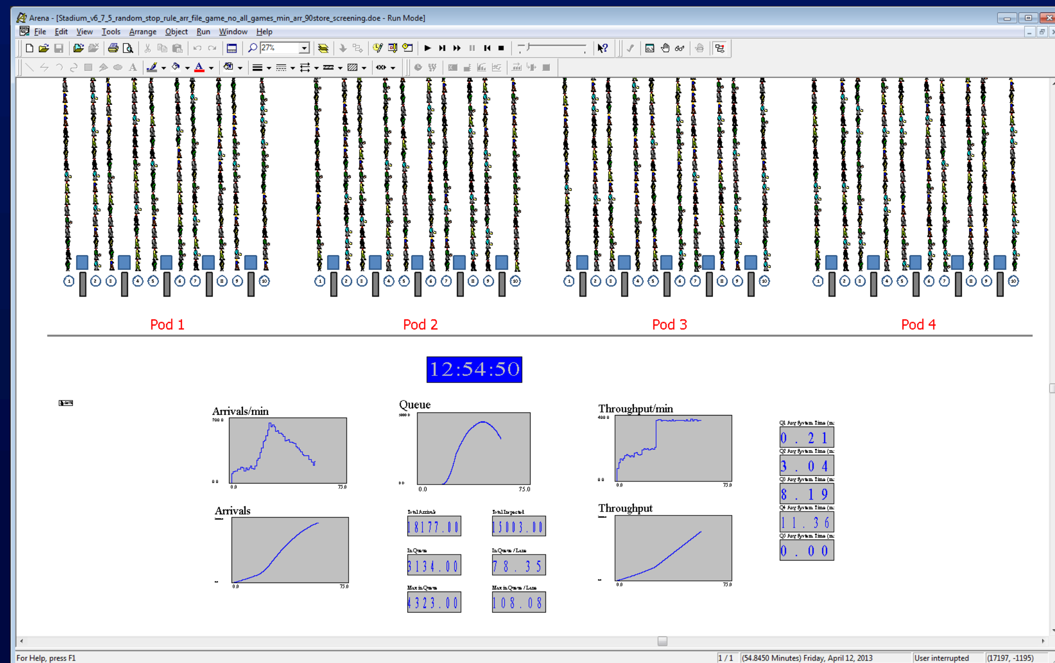
The Simulation Model

Most of the parameters can be obtained by ***choosing a representative game***



- Parameters
  - Arrival rates
  - Number of lanes
  - Wanding times
  - Pat-down times
  - Magnetometer times

- Screening Strategy
  - Switching inspection type (Y/N)
    - Number of patrons in queue to switch the process, or
    - Time of switch
  - Does phase 2 include randomization? (Y/N)
    - Ratio of patrons in each type of inspection in the randomization

The model output file includes:

– Total Arrivals
– Total Arrivals @ kickoff
– Maximum number in Queue
– **In Queue @ kickoff**
– **Queue clearance time**
– Screening switch time
– Number of patrons inspected by different procedures
– **Max Waiting Time per patron**

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Conclusion from Data Analysis and Modeling

- If you want to do more rigorous inspection of all the patrons, you need to get more of them to arrive early and enter the stadium.
- You have to ***"change the culture"***

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Data Analysis

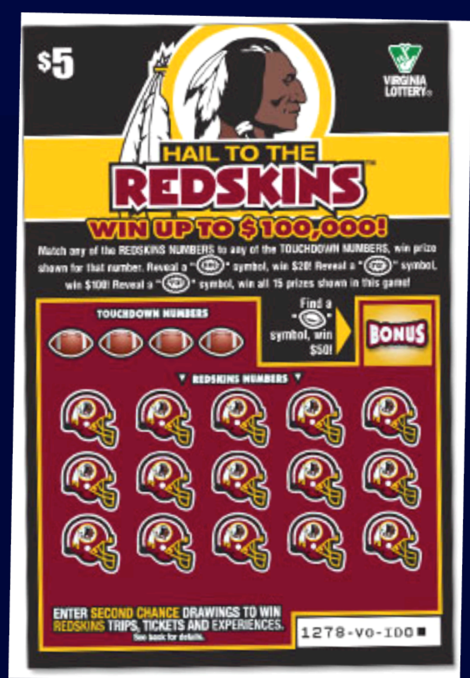
- "Changing the culture" requires changing the way people behave – through policy changes.
- Create incentives for people to arrive early
- ***½ price beer 2 hours before kickoff***

Data Analysis

- "Changing the culture" requires changing the way people behave – through policy changes.
- Create incentives for people to arrive early
- ***Allow patrons to walk on the field if arrive early***

Data Analysis

- "Changing the culture" requires changing the way people behave – through policy changes.
- Create incentives for people to arrive early
- ***Allow early-arriving patrons to enter a lottery for special prizes***



Credit: washingtoncitypaper.com

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Data Analysis

- "Changing the culture" requires changing the way people behave – through policy changes.
- Create incentives for people to arrive early
- This worked in Oakland, California at the Oakland Coliseum
- Changed the culture

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Future Directions/Next Steps

- ***Simple randomizations and how to implement and test in practice:***
  - When 100% inspection is not feasible, is there a randomized inspection scheme that ensures equal or greater security protection and deterrence benefit?
  - Use our simulation model to help with percentages that can be inspected at each stage before kickoff?
  - Is there a way to implement such a scheme that is practical and ***not subject to being interpreted as profiling?***
    - Random beeper
    - Deck of cards
    - Credit card number to present later in the queue

Example IV: Nuclear Detection in a City

- Big city police departments started experimenting with putting nuclear detectors in police cars.
- We wanted to see if there were enough police cars to give “adequate” coverage to have a high probability of finding a nuclear device.

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Nuclear Detection Using Vehicles

- Distribute GPS tracking and nuclear detection devices to police cars in a metropolitan area.
  - Feasibility: New technologies are making devices portable, powerful, and cheaper.
  - ***Some police departments are already experimenting with nuclear detectors.***
- Send out signals if the vehicles are getting close to nuclear sources.
- Analyze the information (both locations and nuclear signals) to detect potential location of a source.

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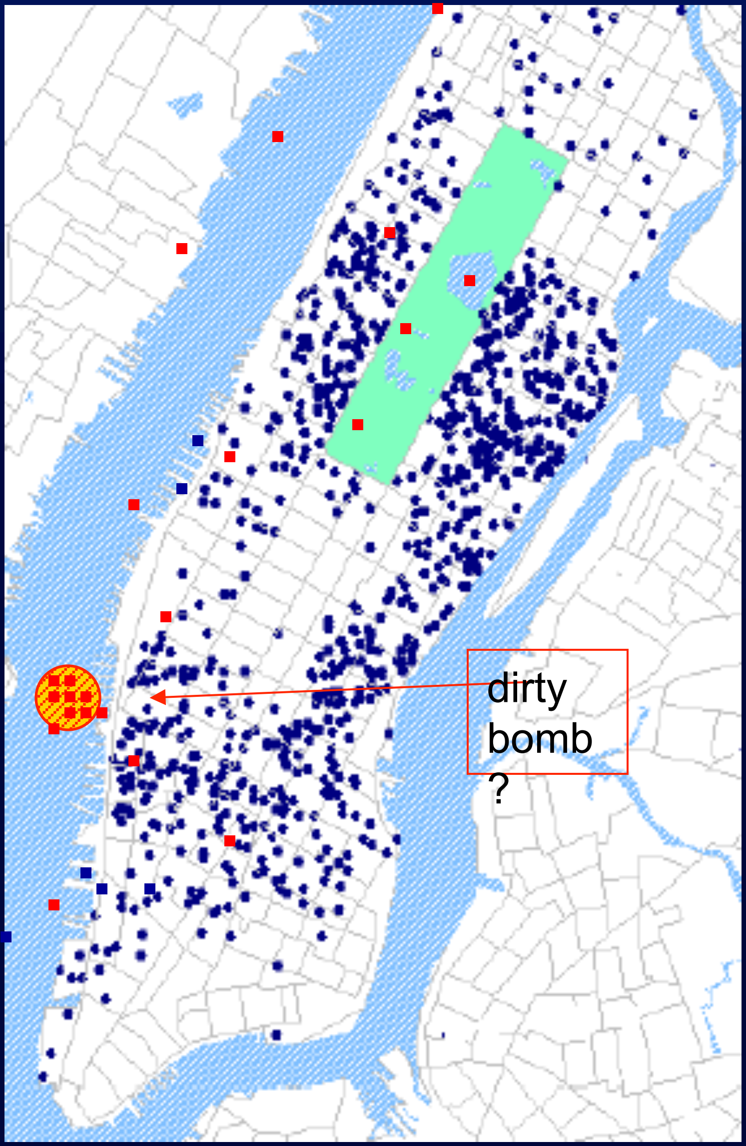
Nuclear Detection using Police Cars

GPS tracking device

+

Nuclear sensor device

Manhattan, New York City
A simulation of police car locations at morning rush hour



Detectors in Vehicles – Model Components

- In our early work, we did not have a specific model of vehicle movement.
- We assumed that vehicles are randomly moved to new locations in the region being monitored each time period.
- If there are many vehicles with sufficiently random movements, this is a reasonable first approximation.

Vehicles – Clustering of Events

- **Definition of Clusters**:
  - Unusually large number of events/patterns clumping within a small region of time, space or location in a sequence
  - A cluster of alarms suggests there is a source
- **Use statistical methodology**:
  - Formal tests: provide statistical significance against random chance.
- **Traditional statistical method is via *Scan Statistics***
  - Scan entire study area and seek to locate region(s) with unusually high likelihood of incidence
  - E.g, use:
    - maximum number of cases in a fixed-size moving window
    - Diameter of the smallest window that contains a fixed number of cases

Vehicles - Simulation

- First stage of work
- Generated data in Manhattan and did a simulation – applying the clustering approach with success
- Used spatclus package in R: software package to detect clusters
- In the simulations, we have considered both moving and stationary sources.

Number of Vehicles Needed

- The required number of vehicles in the surveillance network can be determined by ***statistical power analysis***
  - The larger # of vehicles, the higher power of detection
- An illustrative example:
  - A surveillance network covers area 4000 ft by 10000 ft
    - Roughly equal to the area of the roads and sidewalks of Mid/Downtown Manhattan
  - Vehicles are randomly moving around in the area

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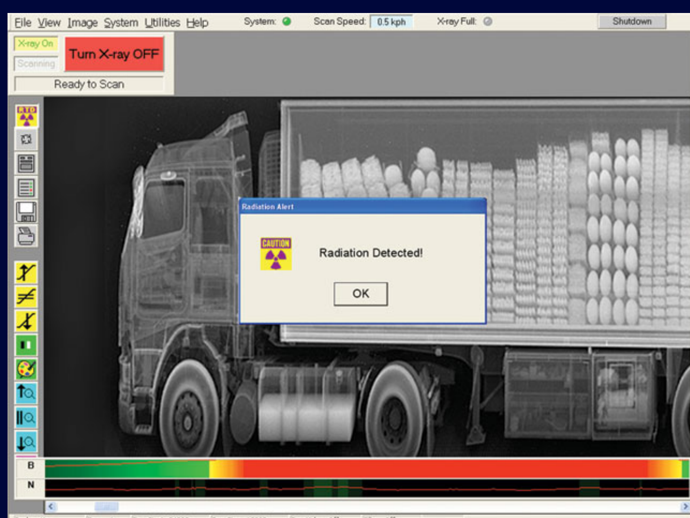
Number of Vehicles Needed

- Fix key parameters
  - Effective range of a working detector
  - False positive & false negative rates for detectors
  - ***The ranges and rates we used are not realistic, but we wanted to test general methods, & not be tied to today's technology***
- A fixed nuclear source randomly placed in the area



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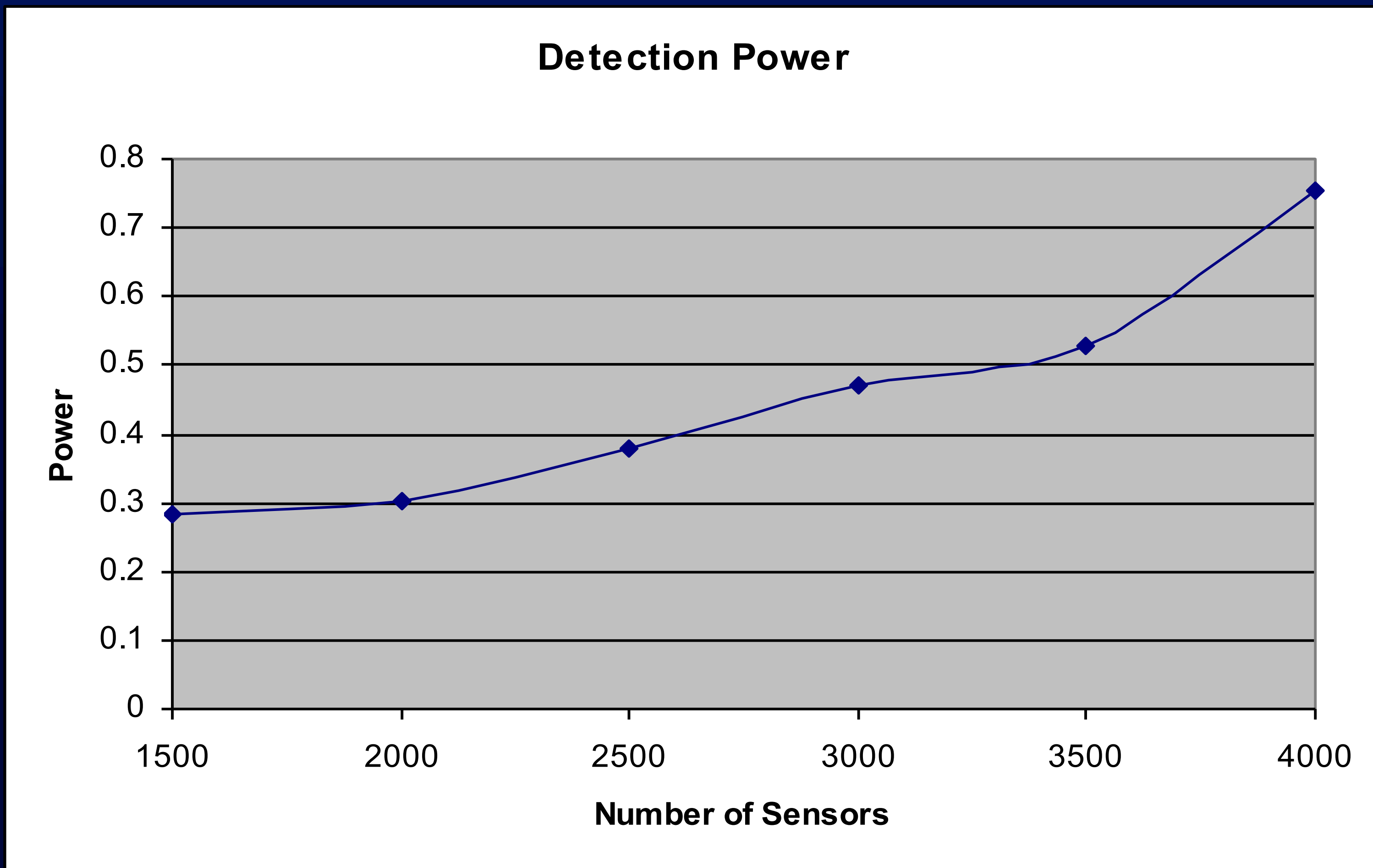
Number of Vehicles Needed

First Model

- Effective range of detector: 150 ft.
- False positive rate 2%
- False negative rate 5%
- Varied number of vehicles (= number of sensors) and ran at least 50 simulations for each number of vehicles.
- For each, measure the ***power*** = P(D=1/S=1) = probability of detection of a source.

Number of Vehicles (Sensors) Needed

- Sensor range=150 feet, false positive=2%, false negative=5%.



Conclusion: Need 4000 vehicles to even get 75% power.

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Number of Vehicles Needed

- NYPD has 3000+ vehicles in 76 precincts in 5 boroughs. Perhaps 500 to 750 are in streets of Mid/Downtown Manhattan at one time.
- ***Preliminary conclusion: The number of police cars in Manhattan would not be sufficient to even give 30% power.***

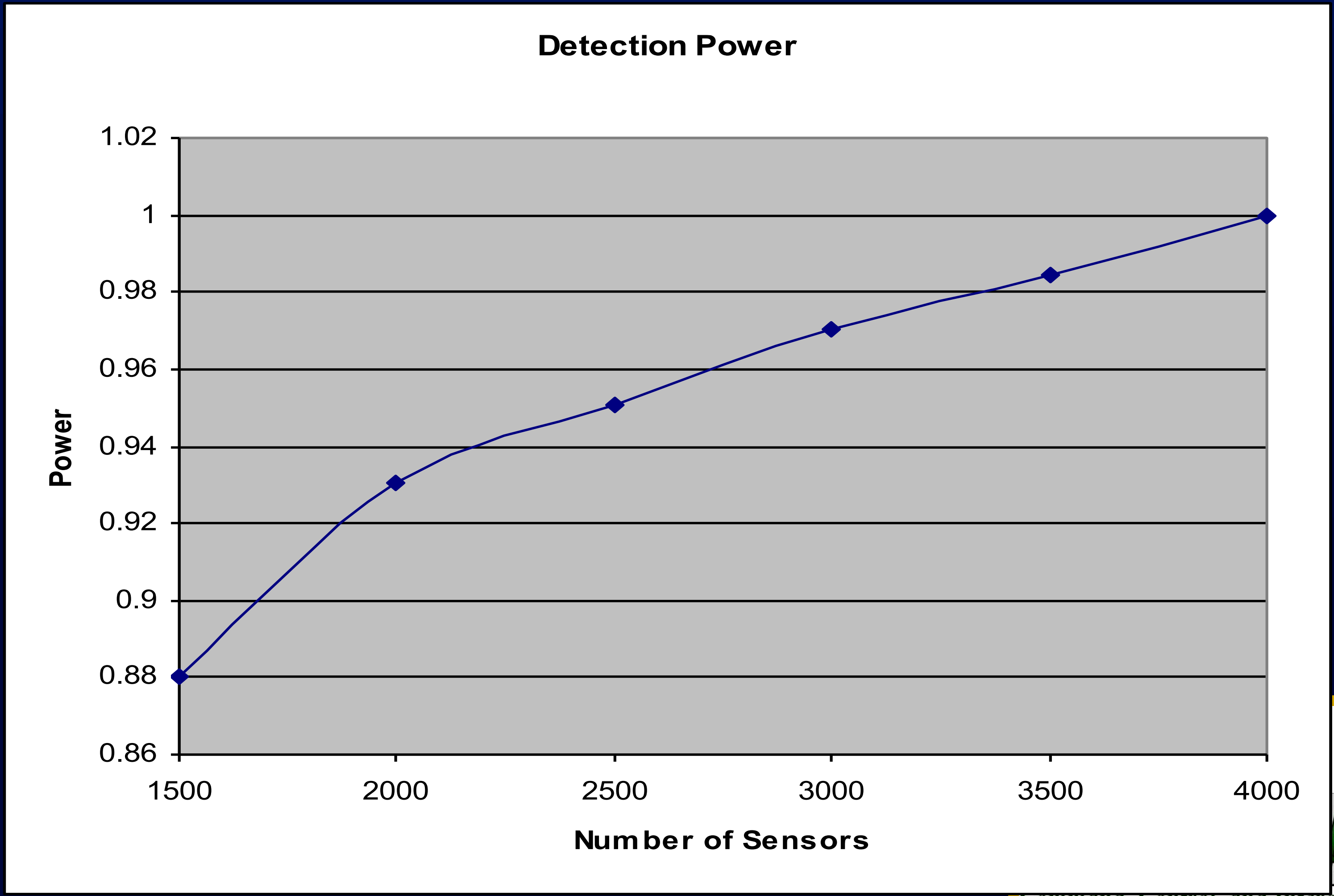
Modified Model

- What if we have a better detector, say with an effective range of 250 ft.
- Don't change assumptions about false positive and false negative rate

57284308 www.fotosearch.com

Number of Vehicles (Sensors) Needed

- Sensor range=250 feet, false positive=2%, false negative=5%.



Conclusion: 2000 vehicles already give 93% power.

Number of Vehicles Needed

- ***There are not enough police cars to accomplish this kind of coverage.***
- There are other problems with our model as it relates to police cars:
  - Police cars tend to remain in their own region/precinct.
  - Police cars don't move around very randomly and randomness is needed else an adversary can anticipate inspections

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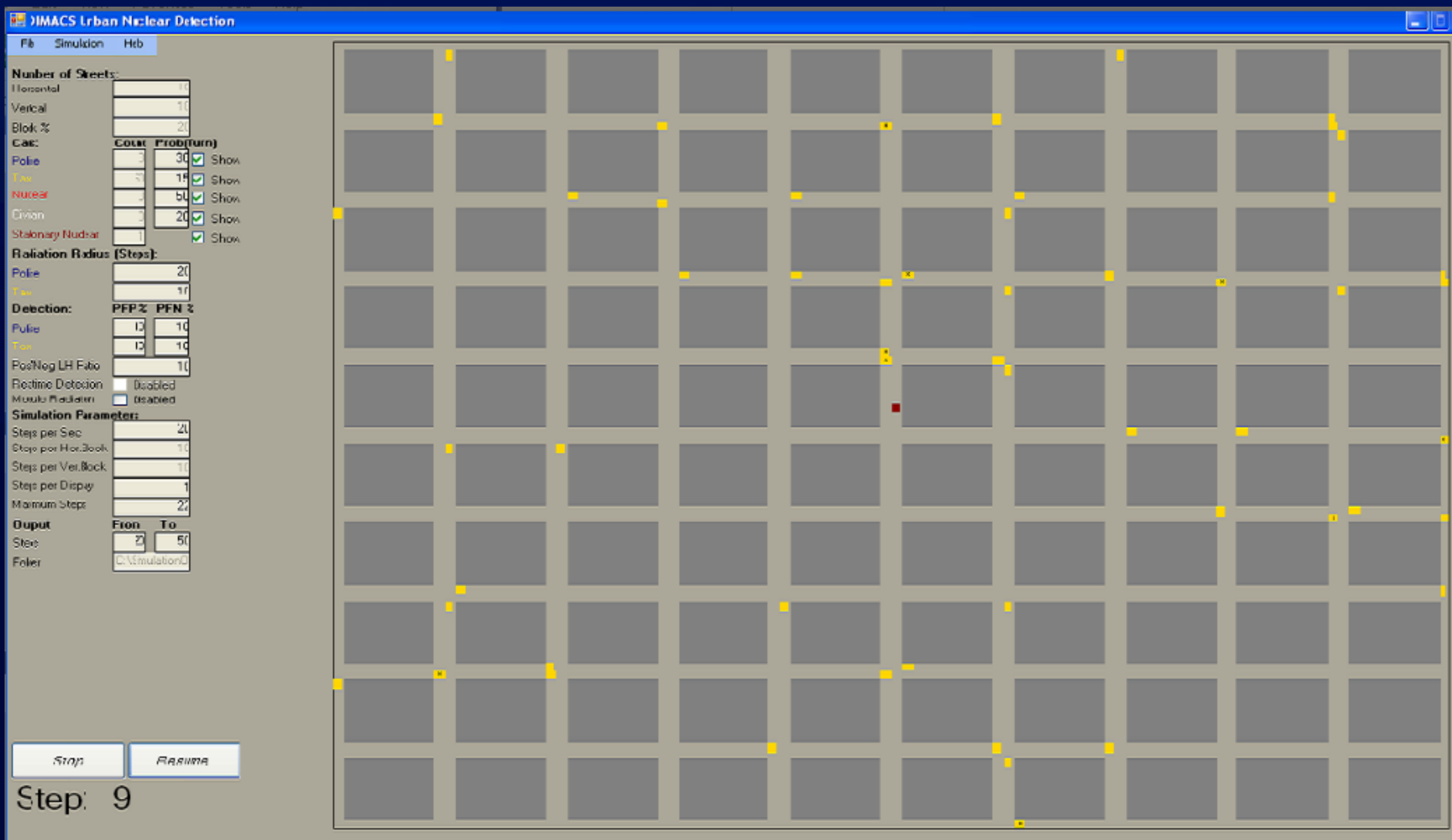
Next Step: Add a Random Movement Model

- Adding a movement model makes the analysis more realistic.
- We take a street network.
- We assume that vehicles move along until they hit an intersection.
- At each intersection, they continue straight or turn left or right according to a random process.

Screen Shot of Simulation Tool for Street Grids & Traffic Movements

Simulation uses ARENA software



Detectors in Vehicles – Simulation

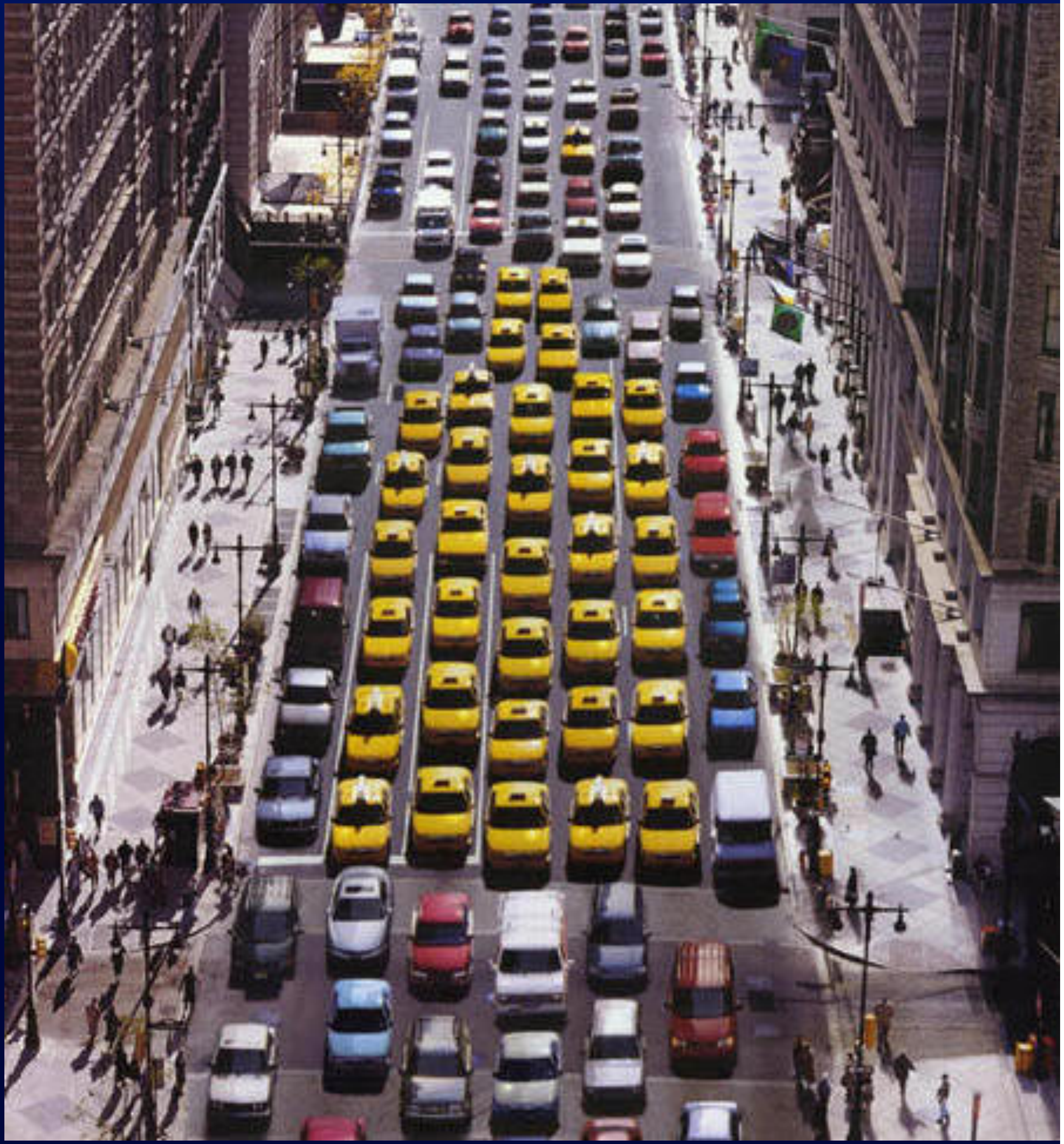
- Take a 25 by 25 block region
  - Roughly the lower Manhattan/ Wall Street area.
  - Use our simulator tool with vehicle movements
  - Again conclude that not enough police cars

Number of Vehicles Needed

- ***But maybe there are enough taxis***
- There are other problems with our model as it relates to police cars:
  - Police cars tend to remain in their own region/precinct.
  - Police cars don't move around very randomly
  - Taxis do move more randomly

Number of Vehicles Needed

- ***Are there enough taxis to achieve a high enough detection power?***
- ***Our models show that there are – at least under our simplifying assumptions***



Nuclear Detection Using Taxicabs

- What is needed to implement the solution of putting nuclear detectors in taxicabs?
- Unfortunately, the police departments in large cities in the US such as New York do not like to depend on the private sector for a substantial role in law enforcement.
- It would require a ***"change in the culture"*** for them to trust taxis

Nuclear Detection Using Taxicabs

- We will need to “educate” the police to the advantages of using taxicabs.
- We will need to create new and better communication and interrelationships between police security operations and taxicab drivers
- If this doesn’t work, we will need to try something different.

Credit: www.taxi-library.org

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Detectors in Cell Phones

- Similar ideas for placing sensors in cell phones have been proposed and tested by the Radiation Laboratory at Purdue University and at Lawrence Livermore National Lab.
- At a meeting with the NYC Police Department, where we presented our taxicab and police car work, we were encouraged to explore applying our methods to the cell phone idea.

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Closing Comments

- Policy analytics alone is not sufficient.
- Policy solutions have to be implemented in practice
- Sometimes, implementation requires a change in the culture.

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Thanks

- **Coast Guard Boat Allocation**: Jake Baron, Endre Boros, Bobby DeMarco, Paul Kantor, Christie Nelson, Matt Oster, Yao Wang, Jim Wojtowicz
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- **Stadium Security**: Alper Almaz, Jonathan Bullinger, Bobby DeMarco, Cindy Hui, Paul Kantor, Alisa Matlin, Ryan Whytlaw, Jim Wojtowicz
- **Nuclear Detection with Taxis**: Rong Chen, Jerry Cheng, Minge Xie

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