

# Optimization in Emergency Management

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# Outline

- Operations Research and Emergency Management
- Two review papers
- Two special on OR & homeland security
  - Interfaces - November 2006
  - IIE Transactions - January 2007
- Geospatial Optimization of Strategic Information and Resources

# Disaster and Emergency

## Disaster

The impact of a natural or human-made hazard that negatively affects society or environment.

## Emergency

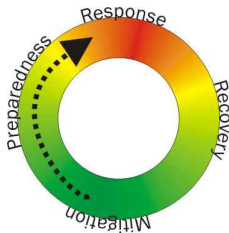
A situation that poses an immediate threat to life, wellbeing, property or environment.

## Disaster Management

The continuous process by which all individuals, groups, and communities manage hazards in an effort to avoid or ameliorate the impact of disasters resulting from the hazards.

# Disaster/Emergency Management

## Disaster/Emergency Management Cycle



**Mitigation:** Efforts to attempt to prevent hazards from developing into disasters altogether, or to reduce the effects of disasters when they occur.

**Preparedness:** Developing plans for actions when the disaster strikes.

**Response:** Mobilization of necessary emergency services and first responders in the disaster area.

**Recovery:** Efforts to restore the affected area to its previous state.

# Operations Research and Management Science

**INFORMS:** The “Science of Better”: the discipline of applying advanced analytical methods to help make better decisions

**EURO:** a scientific approach to the solution of problems in the management of complex systems.

- optimization,
- simulation,
- probability and statistics,
- decision theory,
- control theory,
- system dynamics,
- expert systems,
- ...

# Operations Research and Emergency/Disaster Management

On 26 December 2004 the Indian Ocean tsunami killed in excess of 225,000 people and dislocated millions more in countries spread around the Ocean's rim from Kenya to Indonesia.

The 2001 bombing of the World Trade Center generated direct and indirect losses that most probably will exceed 50 billion US Dollars.

# Operations Research and Emergency/Disaster Management

These are large, intractable problems that test the ability of communities, nations, and regions

- to effectively protect their populations and infrastructure,
- to reduce both human and property loss, and
- to rapidly recover.

They require a discipline with the capability of

- accurate forecasting
- managing risks
- “scientific” decision making for short and long terms
- improving the response.

# Operations Research and Emergency/Disaster Management

## Two Review Papers

There is increasing recognition of the need for study of OR/MS issues in disaster management.

Two review papers for OR/MS research in disaster management are published.

- Altay and Green., 2006 “OR/MS research in disaster operations management”. European Journal of Operational Research
- Wright et al., 2006, “A survey of operations research models and applications in homeland security”. Interfaces.

## Altay and Green (2006)

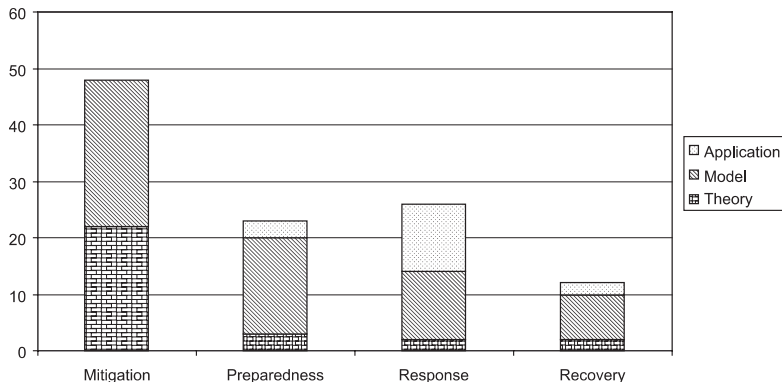
Number of articles	109
<i>Authors' nationality</i>	
	%
	<hr/>
USA	43.1
Other nations	42.2
International	14.7
<i>Publication time</i>	
1980s	12.8
1990s	40.4
Since 2000	46.8

# Altay and Green (2006)

<i>Methodology</i>	
Math Programming	32.1
Probability and Statistics	19.2
Simulation	11.9
Decision Theory and MAUT	10.1
Queuing Theory	9.2
Fuzzy Sets	5.5
Stochastic Programming	3.7
Experts Systems and AI	3.7
Systems Dynamics	1.8
Constraint Programming	0.9
Soft OR	0.9

<i>Disaster type</i>	
Natural	28.4
Man-made	33.1
Humanitarian	0.9
All disasters	37.6

# Altay and Green (2006)



**Figure:** Distribution of research contribution to life-cycles stages of Disaster Operations Management

Model development (57.8%), theory (26.6%), and application (15.6%)

Classified the homeland security literature in three main research areas.

- 1** Countermeasures portfolios (protecting the US from weapons of mass destruction)
  - risks of biological, chemical, radiological and nuclear weapons, and high explosives
- 2** Component-support portfolios (increasing the capabilities of DHS components)
  - Border and transportation security (airline, port, rail, truck)
  - Critical infrastructure protection
  - Cyber Security (information infrastructure)
  - Emergency preparedness and response (location and resource allocation, evacuation models, disaster planning and response)
- 3** Cross-cutting portfolios (other vulnerabilities and risks that extend across the two above)

Recently, two Operations Research journals published special issues in homeland security.

- Interfaces - Homeland security: operations research initiatives and applications - November 2006 - 10 articles
- IIE Transactions - Special issue on homeland security - January 2007 - 8 articles

# Larson *et.al.*, *Responding to Emergencies: Lessons Learned and the Need for Analysis*

Interfaces - Homeland security: operations research initiatives and applications #1

- Analyzing the high-consequence, low-probability events and the consequences of alternative policies of preparedness and response.
- A historical review of five recent major emergencies:
  - the Oklahoma City bombing (1995),
  - the crash of United Airlines Flight 232 (1989),
  - the sarin attack in the Tokyo subway (1995),
  - Hurricane Floyd (1999), and
  - Hurricane Charlie (2004)

# Larson *et.al.*, *Responding to Emergencies: Lessons Learned and the Need for Analysis*

Interfaces - Homeland security: operations research initiatives and applications #1

- Shows the need for additional research to develop decision-oriented, operations research models to improve preparation for and response to major emergencies.
- Local emergency managers need decision guidance regarding
  - evacuation directives, management of near-the scene logistics, triage on the scene and at hospitals, use of volunteers and off-duty personnel, reducing telephone traffic congestion, and integration of response with second- and third-level responders from other jurisdictions.
- The potential use of data mining and statistical inference to glean more real-time information from 911 calls.

# Han et.al., *Global Optimization of Emergency Evacuation Assignments*

Interfaces - Homeland security: operations research initiatives and applications #2

Conventional emergency evacuation plans often assign evacuees to fixed routes or destinations based mainly on **geographic proximity**.

Such approaches can be inefficient if the roads are congested, blocked, or otherwise dangerous because of the emergency.

**A framework for the simultaneous optimization of evacuation-traffic distribution and assignment.**

A county-wide, large-scale evacuation case study.

# Brown *et.al.*, *Defending Critical Infrastructure*

Interfaces - Homeland security: operations research initiatives and applications #3

Optimization models to make critical infrastructure more resilient against terrorist attacks.

Each model features an intelligent **attacker** (terrorists) and a **defender** (us), information transparency, and **sequential actions by attacker and defender**.

Examples of the US Strategic Petroleum Reserve, the US Border Patrol at Yuma, Arizona, and an electrical transmission system.

# Martonosi and Barnett, *How Effective Is Security Screening of Airline Passengers?*

Interfaces - Homeland security: operations research initiatives and applications #4

With a simple mathematical model, exploring the antiterrorist effectiveness of airport passenger pre-screening systems.

These systems often emphasize the need to identify the most suspicious passengers.

Critics often focus on terrorists ability to probe the system and thereby thwart it, but ignore the possibility that the very act of probing can deter attempts at sabotage that would have succeeded.

**Result:** An improved baseline level of screening for all passengers might lower the likelihood of attack more than would improved profiling of high-risk passengers.

# Kaplan et.al., *Tactical Prevention of Suicide Bombings in Israel*

Interfaces - Homeland security: operations research initiatives and applications #5

Suicide bombings are the leading cause of death from terrorism in Israel.

**Counter-terror tactics**, such as the targeted killings or preemptive arrests of terror leaders or suspects, are meant to prevent such attacks.

To investigate whether these tactics are successful, they estimated via **maximum likelihood a family of shot-noise models** to see whether we could predict the rate of suicide bombing attacks as a function of prevention tactics over time.

# Kaplan *et.al.*, *Tactical Prevention of Suicide Bombings in Israel*

Interfaces - Homeland security: operations research initiatives and applications #5

## Results:

- Although preventive arrests appear to lower the rate of suicide-bombing attacks, targeted killings seem to be followed by an increase in the number of suicide bombings.
- The probability of intercepting a suicide bomber en route to an attack increases with the expected number of suicide-bombing attacks. Such an endogenous relationship could imply an **upper limit on the rate of successful suicide bombings**.

# Whitworth *et.al.*, *Designing the Response to an Anthrax Attack*

Interfaces - Homeland security: operations research initiatives and applications #6

Federal, state, and local planners are developing plans for large-scale campaigns to **dispense medications in response to bio-terrorist attack**.

The plans integrate

- supply chain operations,
- administrative and clinical processes, and
- client logistics.

# Whitworth *et.al.*, *Designing the Response to an Anthrax Attack*

Interfaces - Homeland security: operations research initiatives and applications #6

**Discrete-event simulation** to help one community develop its plan for responding to an anthrax attack.

Simulation models enabled evaluation of candidate points of dispensing (PODs), alternative dispensing processes, staffing plans, and traffic-management strategies.

Determined how many PODs the community would need, how to staff them, and how to manage client traffic and parking.

# *Aaby et.al., Montgomery Countys Public Health Service Uses Operations Research to Plan Emergency Mass Dispensing and Vaccination Clinics*

Interfaces - Homeland security: operations research initiatives and applications #7

To curb outbreaks of contagious diseases, county health departments must set up and operate clinics to dispense medications and vaccines.

Carefully planning these clinics in advance of such an event is difficult and important.

Developed and implemented operations research models to improve clinic planning for the Montgomery County (Maryland) Public Health Services.

# *Aaby et.al., Montgomery Countys Public Health Service Uses Operations Research to Plan Emergency Mass Dispensing and Vaccination Clinics*

Interfaces - Homeland security: operations research initiatives and applications #7

## Includes

- discrete-event simulation models and
- capacity-planning and
- queueing-system models.

Also developed guidelines for the physical design of clinics based on general queueing principles and our own experiences.

# Miller *et.al.*, *Responding to Bioterrorist Smallpox in San Antonio*

Interfaces - Homeland security: operations research initiatives and applications #8

**Discrete-event simulation** to help the San Antonio public health and acute medical care communities to plan their response to a bioterrorist attack.

The resources and strategies needed for an effective response.

## **Result:**

- A **mixture** of public-health measures designed to stop the spread of the disease would form a more robust and effective response than any single measure

# Lee et.al., Large-Scale Dispensing for Emergency Response to Bioterrorism and Infectious-Disease Outbreak

Interfaces - Homeland security: operations research initiatives and applications #9

A **simulation** and **decision-support system** (RealOpt) for planning large-scale emergency dispensing clinics to respond to biological threats and infectious-disease outbreaks.

The system allows public-health administrators to investigate clinic-design and staffing scenarios quickly.

The system incorporates **efficient optimization technology** seamlessly interfaced with a simulation module.

The simulation studies we present explore facility-layout and staffing scenarios for an actual anthrax emergency drill, and we discuss post-event analysis.

# Lee et.al., *Large-Scale Dispensing for Emergency Response to Bioterrorism and Infectious-Disease Outbreak*

Interfaces - Homeland security: operations research initiatives and applications #9

A real-time decision-support system through careful design of a stand-alone simulator, coupled with powerful and tailored optimization solvers.

Analysis of **what-if scenarios**, and serves as an invaluable tool for operational planning and dynamic, on-the-fly reconfigurations of large-scale emergency dispensing clinics.

Performing **virtual field exercises** on the decision-support system, offering insight into operations flow and bottlenecks when mass dispensing is required for a region with a large population.

Two stochastic network interdiction models for thwarting nuclear smuggling.

- The smuggler travels through a transportation network **maximizing the probability of evading detection**
- The interdictor installs radiation sensors **minimizing the evasion probability**

The problem is **stochastic** because the smugglers origin-destination pair is known only through a probability distribution at the time when the sensors are installed.

- In **the first model**, the smuggler knows the locations of all sensors and the interdictor and the smuggler **agree** on the probabilities that the smuggler will be detected while traversing the arcs of the transportation network.
- In **the second model**, the interdictor and smuggler can have **differing perceptions** of these network parameters. The smuggler is aware of only a **subset** of the sensor locations.

# Lim and Smith, *Algorithms for discrete and continuous multicommodity flow network interdiction problems*

IIE Transactions - Special issue on homeland security #2

An attacker disables a set of network arcs in order to **minimize the maximum profit** that can be obtained from shipping commodities across the network.

The attacker is assumed to have some budget for destroying arcs, and each arc is associated with a positive interdiction expense.

They examine the problems in which interdiction is

- **discrete**: each arc must either be left alone or completely destroyed,
- **continuous**: the capacities of arcs may be partially reduced.

# Lim and Smith, *Algorithms for discrete and continuous multicommodity flow network interdiction problems*

IIE Transactions - Special issue on homeland security #2

- For **the discrete problem**, a linearized model for optimizing network interdiction is developed and compared to a penalty model that does not require linearization constraints.
- For **the continuous case**, an optimal partitioning algorithm along with a heuristic procedure for estimating the optimal objective function value is given.

# Gong and Batta, *Allocation and reallocation of ambulances to casualty clusters in a disaster relief operation*

IIE Transactions - Special issue on homeland security #3

Two problems are considered: Ambulance allocation and reallocation for a post-disaster relief operation.

In **the allocation problem**;

- Allocating the **correct number of ambulances to each cluster** at the beginning of the rescue process.
- A deterministic model which depicts how a cluster grows after a disaster strikes.
- Based on the model and given a number of ambulances, methods to calculate **critical time measures**, e.g., the completion time for each cluster.
- Then they present two iterative procedures to optimize the make-span and the weighted total flow time, respectively.

# Gong and Batta, *Allocation and reallocation of ambulances to casualty clusters in a disaster relief operation*

IIE Transactions - Special issue on homeland security #3

## In the reallocation problem;

- Ambulance reallocation problem on the basis of a discrete time policy.
- The benefits of redistribution: providing service to new clusters and fully utilizing ambulances.
- The objective is **minimizing the make-span**.
- The model permits consideration of the travel distance between clusters.
- Case study: An earthquake scenario in Northridge, CA.

# *Jia et.al., A modeling framework for facility location of medical services for large-scale emergencies*

IIE Transactions - Special issue on homeland security #4

- Addresses the particular conditions that arise when **locating facilities to service large-scale emergencies**, such as earthquakes, terrorist attacks, etc.
- Provides a survey of general facility location problems
- Analyze the characteristics of large-scale emergencies
- Propose a general facility location model that is suited for large-scale emergencies.
- Illustrative examples for Los Angeles area.

# Min et.al., *Toward modeling and simulation of critical national infrastructure interdependencies*

IIE Transactions - Special issue on homeland security #5

- Critical infrastructure networks that deliver power, petroleum, natural gas, water, and communications.
- Its economic health depends on a number of other infrastructure networks that link residences, industries, commercial sectors, and transportation sectors.
- The national security of the US depends on our ability to understand the vulnerabilities of and analyze the performance of both the individual infrastructures and the entire interconnected system of infrastructures.

# Min et.al., *Toward modeling and simulation of critical national infrastructure interdependencies*

IIE Transactions - Special issue on homeland security #5

- They propose a **modeling and analysis framework** to study the entire system of physical and economic infrastructures.
- The framework uses the existing individual models together with system dynamics, functional models, and nonlinear optimization algorithms.
- Demonstrate its potential use to analyze, and propose a response for, a hypothetical disruption.

# McLay et.al., *Integer programming models and analysis for a multilevel passenger screening problem*

IIE Transactions - Special issue on homeland security #6

- Designing effective aviation security systems for **Passenger pre-screening**
- Effectively using passenger **pre-screening information** to develop **screening strategies**.
- They introduce the Multilevel Passenger Screening Problem (MPSP).

# McLay et.al., Integer programming models and analysis for a multilevel passenger screening problem

IIE Transactions - Special issue on homeland security #6

- In MPSP, a **set of classes** are available for screening passengers, each of which corresponds to several device types for passenger screening, where each device type has an associated capacity and passengers are differentiated by their **perceived risk levels**.
- The objective of MPSP is to use pre-screening information to determine the **passenger assignments that maximize the total security subject to capacity and assignment constraints**.
- MPSP is illustrated with examples that incorporate flight schedule and passenger volume data extracted from the Official Airline Guide.

# Chiu *et.al.*, *Modeling no-choice mass evacuation using a dynamic traffic flow optimization model*

IIE Transactions - Special issue on homeland security #7

- A network transformation and demand specification approach for **no-notice evacuation** modeling. (when any large and unexpected incident occurs)
- Formulating the problem in an dynamic traffic assignment model.
- Combined with a demand specification method, the problem is formulated as a linear programming model.
- A numerical example is given to illustrate the modeling procedure and solution properties.
- Real-time operational issues and data requirements are also discussed.

# Qiao et.al., *Allocating security resources to a water supply network*

IIE Transactions - Special issue on homeland security #8

- A method for allocating a security budget to a **water supply network** so as to maximize the networks resilience to physical attack.
- The method integrates max-min linear programming, hydraulic simulation, and genetic algorithms for constraint generation.
- The objective is to find a security allocation that maximizes an attackers marginal cost of inflicting damage through the destruction of network components.
- Illustration of the method on two example networks and investigate its allocation effectiveness and computational characteristics.

# Pacific Rim Visualization and Analytics Center (PARVAC)

The Pacific Rim Visualization and Analytics Center (PARVAC) is one of five regional visual analytics centers with core funding from the Department of Homeland Security.

- GOSIR  
A platform of models and algorithms for decision support in emergency management
- JITC3 Just-in-time mobile command and control environment  
Command post for deployment with emergency response personnel which optimizes situational awareness and responder flow during an emerging event.

# Pacific Rim Visualization and Analytics Center (PARVAC)

- RimSim: First response simulator for common Pacific Rim threats  
A modular software-based system to simulate first responder communications, shared artifacts and response actions in order to evaluate and improve level of distributed cognition.
- VisSearch: Visual Search Improving visual search through gaze detection strategies and technology-mediation.

# Geospatial Optimization of Strategic Information and Resources (GOSIR)

## The Problem

Decisions to support preparedness and response activities for disaster management are challenging because of

- uncertainties of events and
- complications on the availability of real time data.

We developed optimization models for **the location and allocation problems of medical supplies to be used in emergencies** are developed for the Seattle region.

# Geospatial Optimization of Strategic Information and Resources (GOSIR)

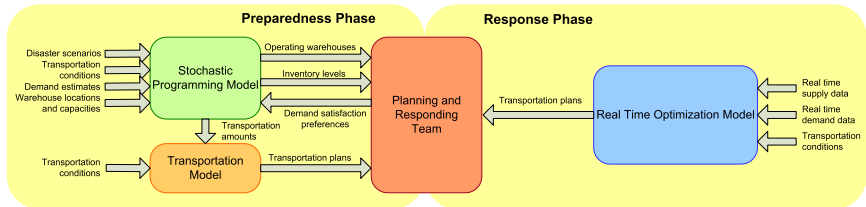
## The Problem

The distribution of supplies requires a series of decisions.

- Before the event occurs
  - The location of the warehouses and
  - their inventory levels for medical supplies are chosen before an event occurs.
- After the onset of the disaster,
  - the disaster the allocation of medical supplies to hospitals is optimized to reduce delivery time.

# Geospatial Optimization of Strategic Information and Resources (GOSIR)

The flow of the models



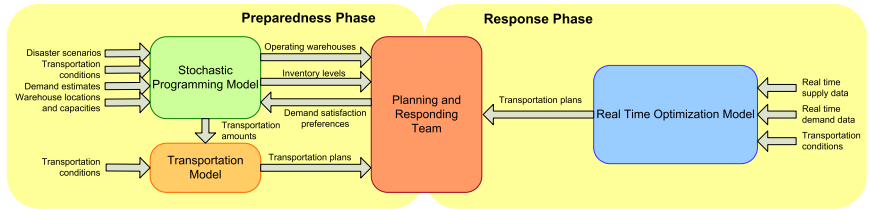
In **the preparedness phase**,

## Stochastic programming model

- enables the selection of the warehouses and
- determines their inventory levels by balancing of risks of disasters with timely delivery of medical supplies

# Geospatial Optimization of Strategic Information and Resources (GOSIR)

## The flow of the models

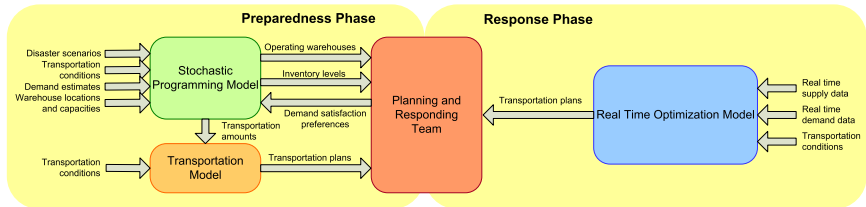


## Transportation model

- transforms the transportation orders to the optimal assignment and routing of vehicles.

# Geospatial Optimization of Strategic Information and Resources (GOSIR)

## The flow of the models



In **the response phase**,

## Real time optimization model

- provides the assignment and routing of vehicles due to the updated transportation conditions and current demand and supply information.

# Geospatial Optimization of Strategic Information and Resources (GOSIR)

## Integration of GOSIR with RimSim

RimSim and GOSIR are integrated in the training of personnel in a command center for disaster situations.

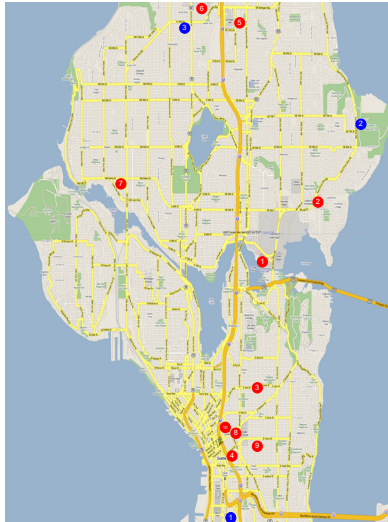
RimSim, which provides the simulation environment for training, is supported by GOSIR for optimal decisions.

In the response phase, as the real time supply and demand information are being collected, GOSIR provides real time decision support to the player for the transportation decisions.

# Case Study: two earthquake scenarios for Seattle

- Seattle Fault Earthquake (M6.7)
- Cascadia Fault Earthquake (M9.0)

# Case Study: two earthquake scenarios for Seattle



# Case Study: two earthquake scenarios for Seattle

## Case Data

### Demand of hospitals

	Seattle Fault	Cascadia Fault
1.	647	734
2.	535	711
3.	335	425
4.	323	499
5.	583	753
6.	530	794
7.	598	690
8.	355	487
9.	395	439
10.	309	462

### Warehouse capacities

- 2,500
- 3,000
- 1,500

### Probabilities

Seattle Fault	Cascadia Fault
40%	60%

### Routes

62 routes, which include all warehouse – hospital combinations and alternatives, are assigned for this case.

### Supply types

The case solved for one type of medical supply.

# Case Study: two earthquake scenarios for Seattle

## Results of the stochastic programming model

- All three warehouses are utilized.
- 100% of the demands of hospitals are satisfied.

### Inventory levels of warehouses

1.	2,312
2.	2,182
3.	1,500

### Transportation amounts

	Seattle Fault			Cascadia Fault			Total	
	W-1	W-2	W-3	W-1	W-2	W-3		
1.		647			647		734	
2.		535			535		711	
3.	335			335		425	425	
4.	323			323	499		499	
5.		211	372	383		47	706	
6.			530	530		794	794	
7.			598	598		690	690	
8.	355			355	487		487	
9.	395			395	439		439	
10.	309			309	462		462	
<b>Total</b>	<b>1,717</b>	<b>1,393</b>	<b>1,500</b>	<b>4,610</b>	<b>2,312</b>	<b>2,182</b>	<b>1,500</b>	<b>5,994</b>

## Results of the transportation model

Route	Seattle Fault			Cascadia Fault		
	W	Hospitals on Route		Route	W	Hospitals on Route
3	1	3		3	1	3
		335				425
4	1	4		4	1	4
		323				499
8	1	8		8	1	8
		355				487
9	1	9		9	1	9
		395				439
10	1	10		10	1	10
		309				462
11	2	1		11	2	1
		182				234
12	2	2		12	2	2
		500				401
15	2	5		15	2	5
		211				47
26	3	6		17	2	7
		500				500
27	3	7		25	3	5
		500				500
47	2	2	1	26	3	6
		35	465			500
56	3	6	5	47	2	2
		30	372			1
57	3	7	1	49	2	2
		98	0			7
			0			310
				56	3	6
						5
						294
						206