Optimizing Supply Chains in Military Operations

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Preliminaries

- Military operations are rare events;
- During peacetime the military consumes resources;
- Peacetime SC is similar to a business SC (MinCost, best business practices, efficiency);
- Strategic decisions regarding wartime SC are taken during peacetime (national supply levels, logistics force structure, doctrine), *F(threat, national capabilities);*
- Operational and tactical decisions are taken during wartime: *F(theater, scenario).*

Logistics Support Chain

Planning, implementing and controlling:

- **Supply**
- Mobilization
- Ordnance
- Maintenance
- Medical

Strategic: national resources and capabilities

Operational: theater-level deployment and employment

Tactical: Combat unit's logistics

- Decision levels
- Sections of the SC

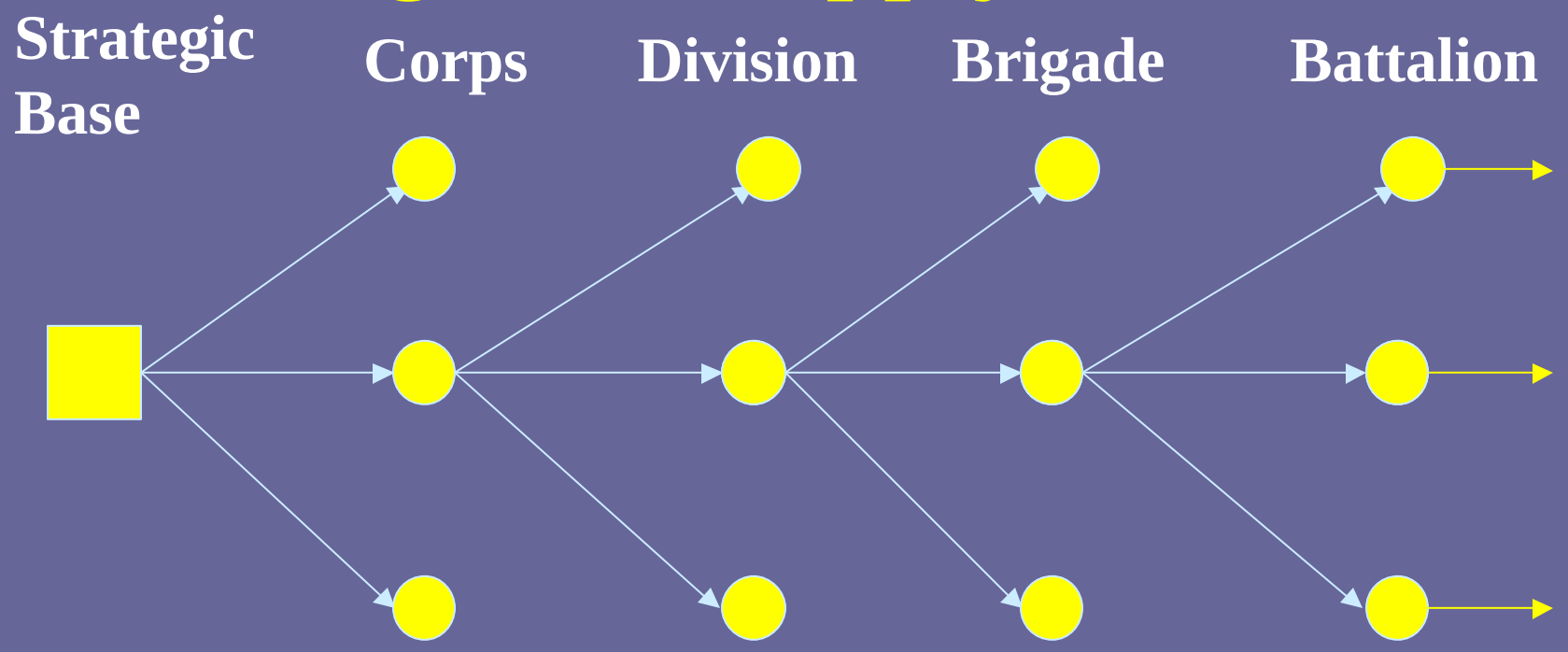
The General Problem

Design a supply chain that
best responds to the battlefield
needs during a military operation
in a given theater (strategic and operational aspects)

Overview

- Characteristics of a military supply chain during an operation
- Comparing Mil. SC with Bus. SC
- Types of uncertainty in Mil. SC
- Descriptive model
- Prescriptive model

Logistics Supply Chain



- ~ complete *k*-array rooted tree, *k*=3-5
- Main problem: how much to allocate (deploy) to each unit
- *F(force, theaters of operations, enemy, threat, doctrine)*

Trendy Buzz-Terms and Tenets

- *Velocity management*
- *Minimum footprint*
- *Just-in-case vs. just-in-time*
- *Trade mass for velocity*

Minimize Tail, Maximize Response

Retail vs. Military Supply Chains

Criterion	Retail	Military
Operation	routine, long-term, S - L	rare, short-term, XL-scale
Environment	neutral	hostile
Uncertainty	demand, cost, lead time	+ deployment, survival
Cost Consideration	mostly economical	mostly operational
Graph of LogNet	static	dynamic
Flow	sparse, (trucks)	massive, (convoys)
Modeling Approach	microscopic	macroscopic

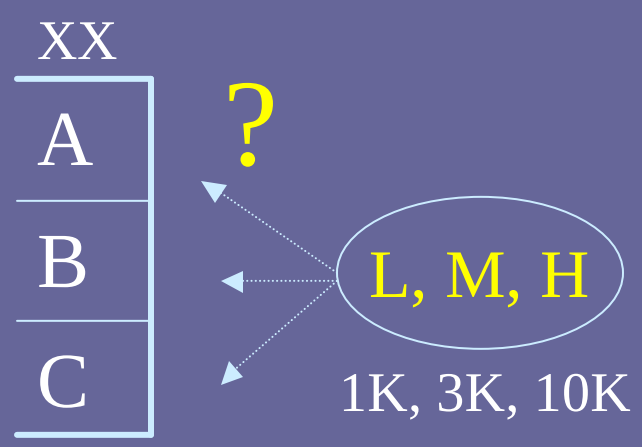
Service Level Measures	relatively relaxed	relatively strict

Service Level Measures

Retail	Military
$\Pr[d_i \text{ is satisfied}] \geq 0.95,\ i,\ldots,n$ ➔"On average 95% of customers are satisfied all the time" ➔ Expected Value	$\Pr[d_i \text{ is satisfied},\ i=1,\ldots,n] \geq 0.95$ ➔"All customers are satisfied at least 95% of the time" ➔ Chance Constraint

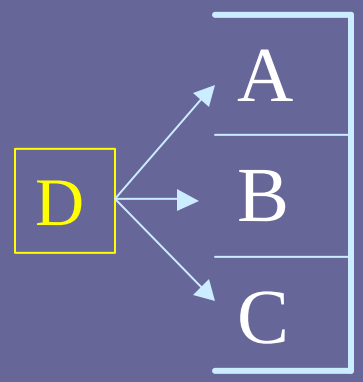
But reasonably realistic

A Simple Risk Pooling Example



	Day	
I	II	III
H ➔	H	H
M ➔	M	M
L ➔	L	L

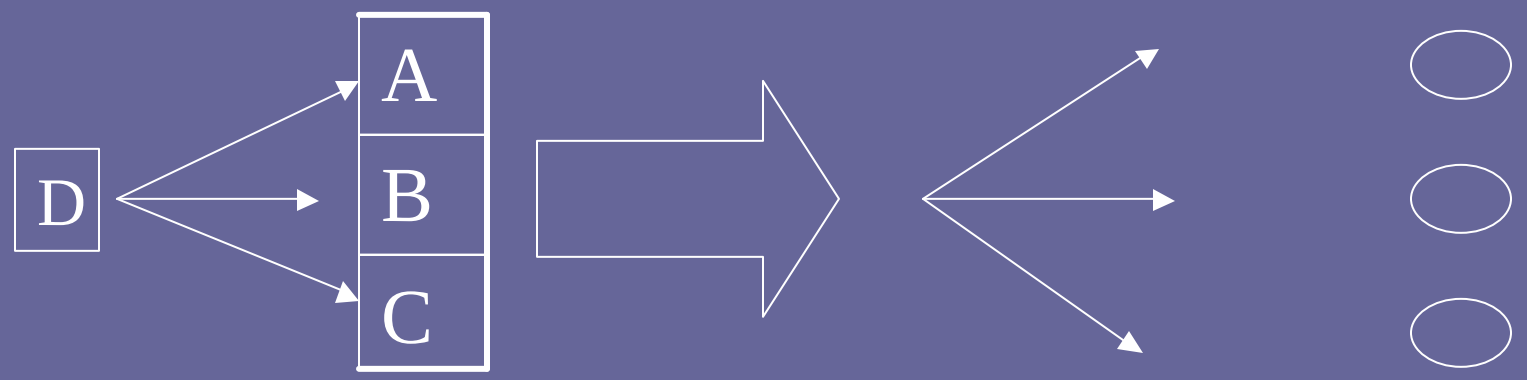
100% response ➔ Corps base-stock = $3 \times 3 \times 10K = 90K$



100% response ➔ Corps base-stock =

$(3 + 2) \times 10K = 50K$

Types of Uncertainty



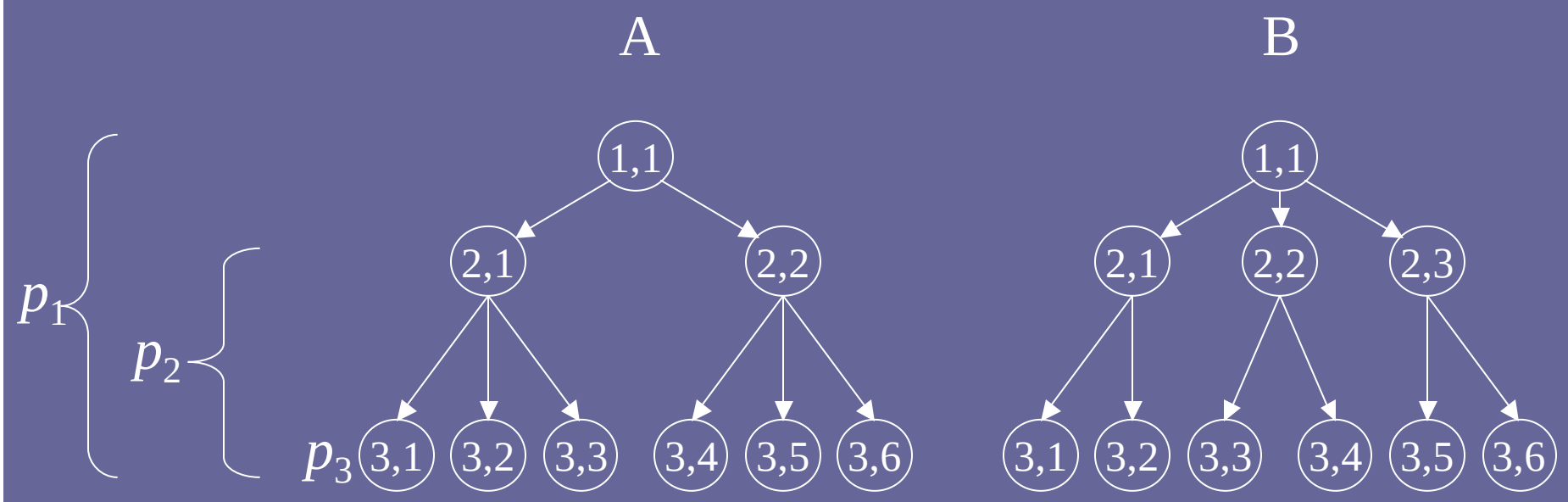
Delivery Uncertainty

Initial Scenario Uncertainty

Transition Uncertainty

Demand (statistical) Uncertainty

Descriptive (Static) Approach



d_{3j} = Demand at node (3,j), j=1,…,6. $d_{3j} \sim F_j$

x_{ij}(A) (x_{ij}(B)) = Inventory deployed at node (i,j) in Plan A(B).

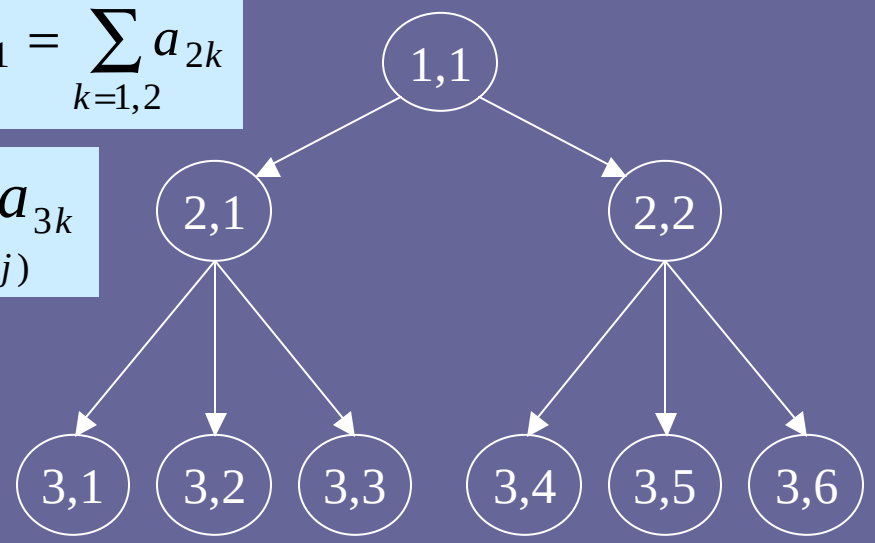
p_i = Level i timeliness probability

Descriptive (Static) Approach cont.

$$d_{11} = \sum_{k=1,2} a_{2k}$$

$$a_{2j} = Max\{0, d_{2j} - x_{2j}\};\ d_{2j} = \sum_{k \in S(2,j)} a_{3k}$$

$$a_{3j} = Max\{0, d_{3j} - x_{3j}\}$$



Sufficiency Probabilities:

$$R_1 = R(x_{11}, x_{21}, \ldots, x_{36}) = \Pr[d_{11} \le x_{11}]$$

$$R_2 = R(x_{21}, \ldots, x_{36}) = \Pr[d_{21} \le x_{21}, d_{22} \le x_{22}]$$

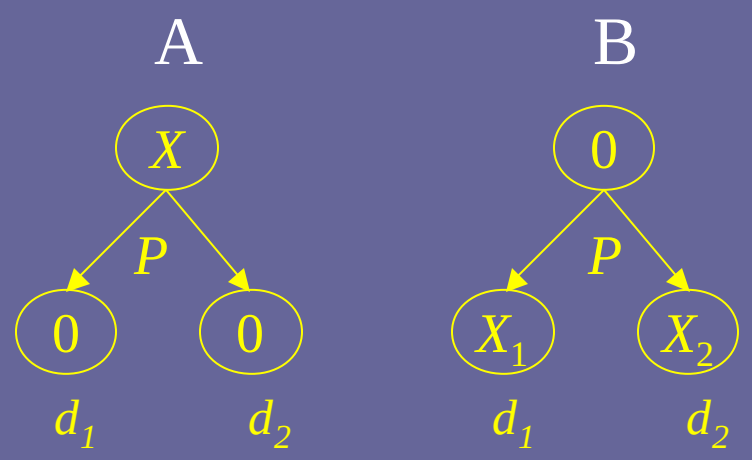
$$R_3 = R(x_{31}, \ldots, x_{36}) = \Pr[d_{3j} \le x_{3j},\ j = 1, \ldots, 6]$$

Descriptive (Static) Approach cont.

Response Probability: $Q = p_1R_1 + p_2(1-p_1)R_2 + p_3(1-p_1)(1-p_2)R_3$

$$\text{(Plan A) } \mathbb{P} \text{ (Plan B) iff } Q_A > Q_B$$

Example

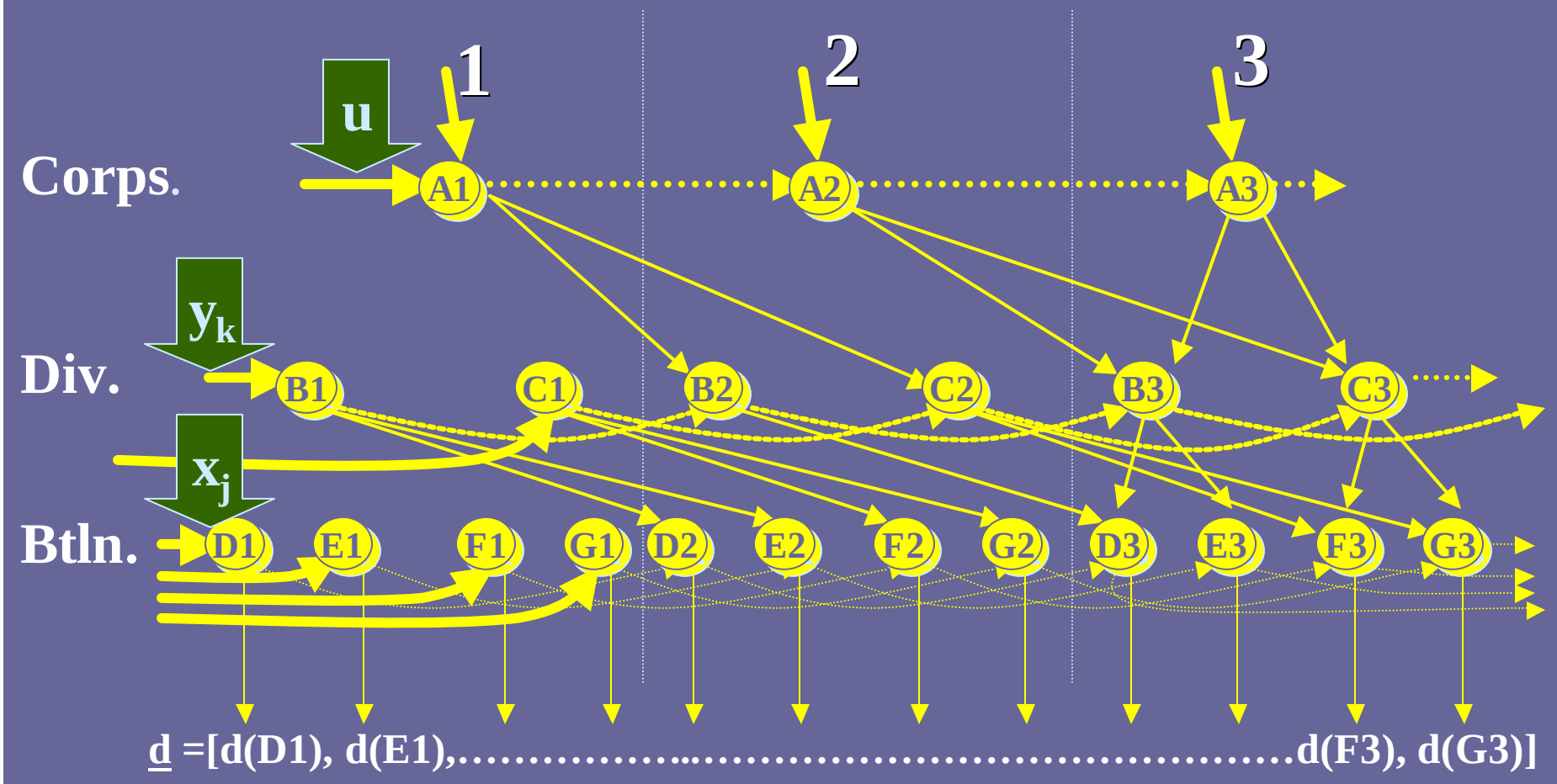


A $\mathbb{P}$ B iff

$$p \geq \frac{\Pr[d_1 \leq X_1, d_2 \leq X_2]}{\Pr[d_1 + d_2 \leq X]}$$

More details & examples:
M. Kress, *Operational Logistics*, Kluwer, 2002

Prescriptive (Dynamic) Approach
(Inter-Temporal Network)

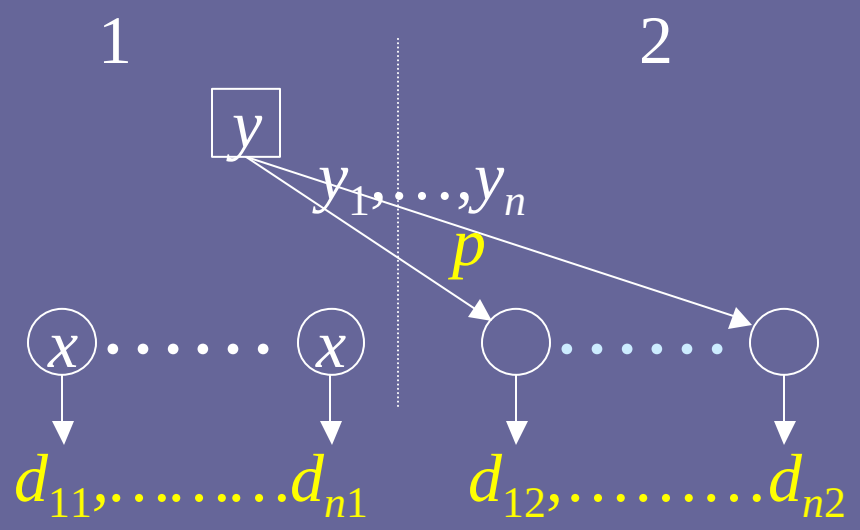


d =[d(D1), d(E1),……..……d(F3), d(G3)]

Features of ITN

- Nodes and edges may be added and removed
- Slopes of diagonal edges represent lead-times
- Scenarios (demand vector, graph topology) are simulated
- Initial supply levels - *F(initial demand, transportation needs, nodes/edges survivability)*
- Specific replenishing decision rules may be explicitly represented

Example: Two Periods Two Levels



$x = ?$

$y = ?$

$$Min\ \ nc_1 x + c_2 y$$

st

$$\Pr[d_{1j} \le x,\ j = 1,\ldots,n] \ge Q_1,$$

$$\Pr[d_{2j} + d_{1j} \le x + y_j,\ j = 1,,,.n]p + \Pr[d_{2j} + d_{1j} \le x,\ j = 1,\ldots,n](1-p) \ge Q_2$$

$$\sum_{j=1}^{n} y_j - y \le 0$$

$$x, y, y_j \ge 0$$

CCP – Deterministic Equivalent

$$(d_{t1},\ldots,d_{tn}) \sim F_t \;; \qquad G = F_1 * F_2$$

$$Min \;\; nc_1 x + c_2 y$$

$$st$$

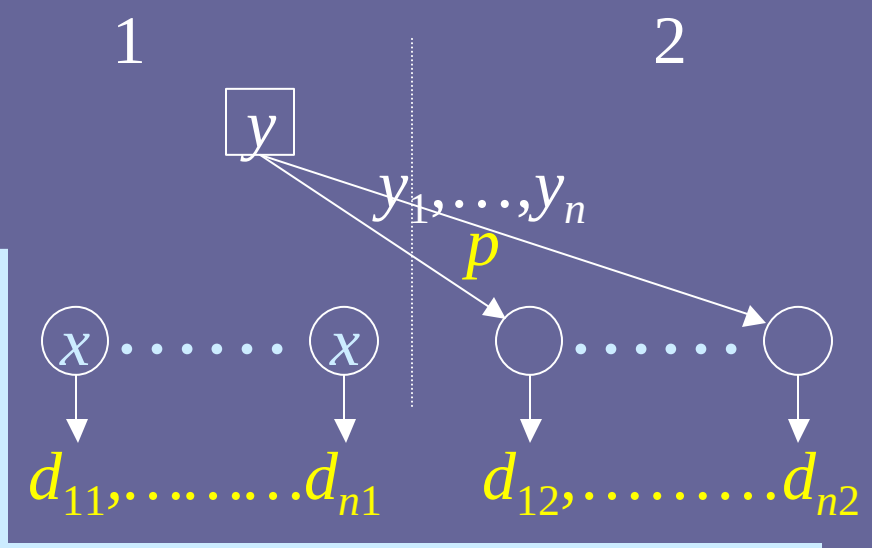
$$x \geq F_1^{-1}(Q_1)\}$$

$$pG(x+y_1,\ldots,x+y_n) + (1-p)G(x,\ldots,x) \geq Q_2$$

$$\sum_{j=1}^{n} y_j - y \leq 0$$

$$x, y, y_j \geq 0$$

Recourse



$$Min\ nc_1x + c_2y$$

$$st$$

$$x \geq \{F_1^{-1}(Q_1)\}$$

$$p\int_0^{\infty} F_2(x + y_j(d_{1j}) - d_{1j} / d_{1j};\ j = 1,\ldots,n)dF_1(d_{11},\ldots,d_{1n}) + (1-p)G(x) \geq Q_2$$

$$\sum_{j=1}^{n} y_j(d_{1j}) - y \leq 0 \quad \text{for all possible vectors } (d_{11},\ldots,d_{1n})$$

$$x, y, y_j(d_{1j}) \geq 0$$

Looking At Scenarios

- Scenario at Period t: $\{d_{t1}^{s}, d_{t2}^{s}, \ldots, d_{tn}^{s}\}$, t=1,2
- $s_1 = 1,\ldots,S_1$; $s_2 = 1,\ldots,S_2$
- $\Pr[s_1] = q_1(s_1)$; $\Pr[s_2] = q_2(s_2)$

First Period

$$Min\ \ x$$

$$x - u_{s_1} d_{1j}^{s_1} \geq 0 \qquad j = 1,\ldots,n,\ \ s_1 = 1,\ldots,S_1$$

$$\sum_{s_1=1}^{S_1} u_{s_1} q_1(s_1) \geq Q_1$$

$$x \geq 0,\ u_{s_1} \in \{0,1\}$$

The Two-Periods Problem

$$Min \quad nc_1 x + c_2 y$$

$$st$$

$$\underline{Period \quad I}$$

$$(1) \qquad x - u_{s_1} d_{1j}^{s_1} \geq 0 \qquad j = 1,\ldots, n, \; s_1 = 1,\ldots, S_1$$

$$(2) \qquad \sum_{s_1=1}^{S_1} u_{s_1} q_1(s_1) \geq Q_1$$

$$\underline{Period \quad II}$$

$$(3) \quad x - d_{1j}^{s_1} + y_j^{s_1} - d_{2j}^{s_2} + (1 - u_{s_1,s_2}^{+})M \geq 0$$

$$(4) \quad x - d_{1j}^{s_1} - d_{2j}^{s_2} + (1 - u_{s_1,s_2}^{-})M \geq 0$$

$$(5) \quad p \sum_{s_2=1}^{S_2} q_{2j}(s_1, s_2) u_{s_1,s_2}^{+} + (1-p) \sum_{s_2=1}^{S_2} q_{2j}(s_1, s_2) u_{s_1,s_2}^{-} \geq Q_2, \qquad s_1 = 1,\ldots, S_1$$

$$(6) \quad \sum_{j=1}^{n} y_j^{s_1} - y^{s_1} \leq 0 \qquad s_1 = 1,\ldots, S_1$$

$$(7) \quad y^{s_1} - y \leq 0$$

$$x, y, y^{s_1}, y_j^{s_1} \geq 0, \quad u_s, u_{s_1,s_2}^{+}, u_{s_1,s_2}^{-} \in \{0,1\}$$

Summary

- Military supply chains are rare;
- Supply-related risks are very high and must be explicitly modeled;
- The Logistics network has a dynamic structure;
- Several facets of uncertainty;
- Descriptive and prescriptive models;
- Strict probabilistic criteria;
- Recourse modeling is important and useful (➔ SP).