Optimization of Ammunition Distribution for Military Training

OIDD 612 Final Project: Group 5

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Decision Making Problem and Context

- In 2015, the 2nd Cavalry Regiment's 3 companies were deployed from Vilseck, Germany across three countries in Eastern Europe
  - Company 1: Bulgaria
  - Company 2: Lithuania
  - Company 3: Romania
- Live ammunition is required for training and each location must have a minimum ammunition stockpile
- Ammunition can be shipped to the satellite locations in two ways:
  1) **Central Regional Hub**: Ammunition can be shipped in bulk by a contractor to a central regional hub, the Berlin Airport in Germany
  2) **Direct to Satellite Bases**: When unit commands are able to accurately predict demand, ammunition can be shipped straight to satellite locations

Key

- Berlin Airport
- Satellite Locations
- Direct shipping to Satellite locations
- Route to Berlin Airport
- Shipping routes to satellite locations

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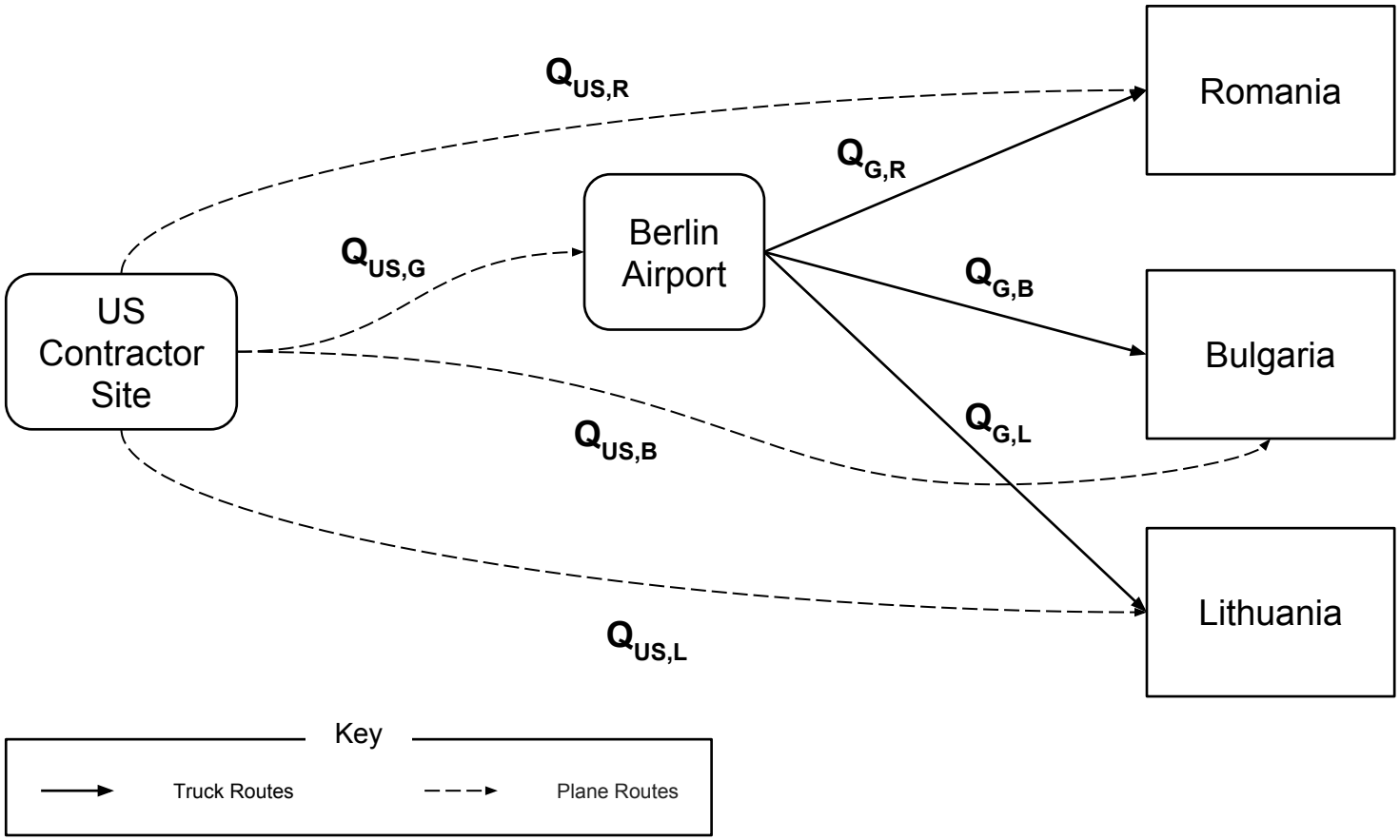
Graphical Illustration of Problem/Model



Data Required and Sources

Data Required

Demand:
- Ammunition demand for each of the 3 satellite locations
- Initial inventory at each location

Storage Costs:
- At Berlin Airport
- At each satellite location

Shipping capacity and costs:
- From contractors to Berlin Airport (airplanes)
- From contractors directly to satellite locations (airplanes)
- From Berlin Airport to satellite locations (shipping trucks)

Capacity constraints at each location

Potential Sources

- Historical demand at each site
- Contractor annual reports
- Primary interviews with key stakeholders
- Open Source Websites:
  - Data.gov
  - fbo.gov
  - dacis.com

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Modeling Approaches and Techniques

- **Linear program** to model basic linear objective function optimization
  - Use solver in excel and Simplex LP
- Use **Monte Carlo** simulation to generate average demand over a normal distribution
  - Each site's demand can be written as N(expected demand, expected variance)
  - Monte Carlo can be used to run trials and generate probabilistic demand distributions
- Extend problem to a **multi-period** scenario
  - Use inventory to link each period's demand constraint
  - Use initial inventories to approximate real world situations
- **Model nuanced phenomena** such as urgency, contractor supply and quality, and bulk purchasing through modifying costs for each remote site

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Simplified Illustration of Model

Decision Variables ('000s)

$Q_{US,G}$ = Quantity shipped from the US to Berlin
$Q_{US,R}$ = Quantity shipped from the US to Romania
$Q_{US,B}$ = Quantity shipped from the US to Bulgaria
$Q_{US,L}$ = Quantity shipped from the US to Lithuania
$Q_{G,R}$ = Quantity trucked from Berlin to Romania
$Q_{G,B}$ = Quantity trucked from Berlin to Bulgaria
$Q_{G,L}$ = Quantity trucked from Berlin to Lithuania, and...
$Y_{i,j}$ = For each of the 7 routes, binary variable to denote whether a route is used

Assumptions / Inputs ('000s)

$FT_{i,j}$ = Fixed transportation cost for the route from i to j
$VT_{i,j}$ = Variable transportation cost for the route from i to j
FS_i = Fixed storage at location i
VS_i = Variable storage cost at location i
D_i = Demand at location i
I_i = Starting inventory at location i
$C_{i,j}$ = Plane / truck capacity for the route from i to j
S_i = Storage capacity at location i

Constraints

- **Demand**: $Q_{US,G} + I_G \geq Q_{G,R} + Q_{G,B} + Q_{G,L,}$ and $Q_{US,i} + Q_{G,i} + I_i \geq D_i$ (for i = R, B and L)
- **Shipping**: $Q_{i,j} \leq C_{i,j}$ for each of the 7 routes
- **Storage Capacity**: $Q_{US,i} + I_i \leq S_i$
- **Non-Negativity**: $Q_{i,j} \geq 0$ for each of the 7 routes

Objective Function ($ '000s)

Minimize **Total Cost = Transportation + Storage Cost**

Transportation Cost: $\sum(FT_{i,j} \times Y_{i,j} + VT_{i,j} \times Q_{i,j})$ for each of the 7 routes

Storage Cost: $\sum [FS_i \times Y_{US,i} + VS_i \times (Q_{US,i} + I_i)]$ for each of the 4 storage locations, i.e. i = G, R, B and L

Simplified Illustration of Model (cont'd)

Route	Transportation Costs						
	Type	Max Capacity	Fixed Cost	Unit Variable Cost	Route used	Quantity shipped	Total Cost
U.S. to Berlin	Plane	1,500	500	20	1	1,500	$30,500
U.S. to Romania	Plane	1,000	250	20	1	500	$10,250
U.S. to Bulgaria	Plane	1,000	250	20	0	0	$0
U.S. to Lithuania	Plane	1,000	250	20	0	0	$0
Berlin to Romania	Truck	1,000	200	40	1	500	$20,200
Berlin to Bulgaria	Truck	1,000	200	30	1	500	$15,200
Berlin to Lithuania	Truck	1,000	200	20	1	500	$10,200
							$86,350

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Simplified Illustration of Model (cont'd)

			Storage Costs			
Location	Demand	Initial Inventory	Max Capacity	Fixed Cost	Unit Variable Cost	Total Storage Cost
Berlin	0	0	5,000	250	50	$75,250
Romania	1,000	0	2,000	200	100	$50,200
Bulgaria	500	0	1,000	100	100	$0
Lithuania	500	0	1,000	100	100	$0
						$125,450

Objective Function	
Transportation Cost	$86,350
Storage Cost	$125,450
Overall Cost	**$211,800**

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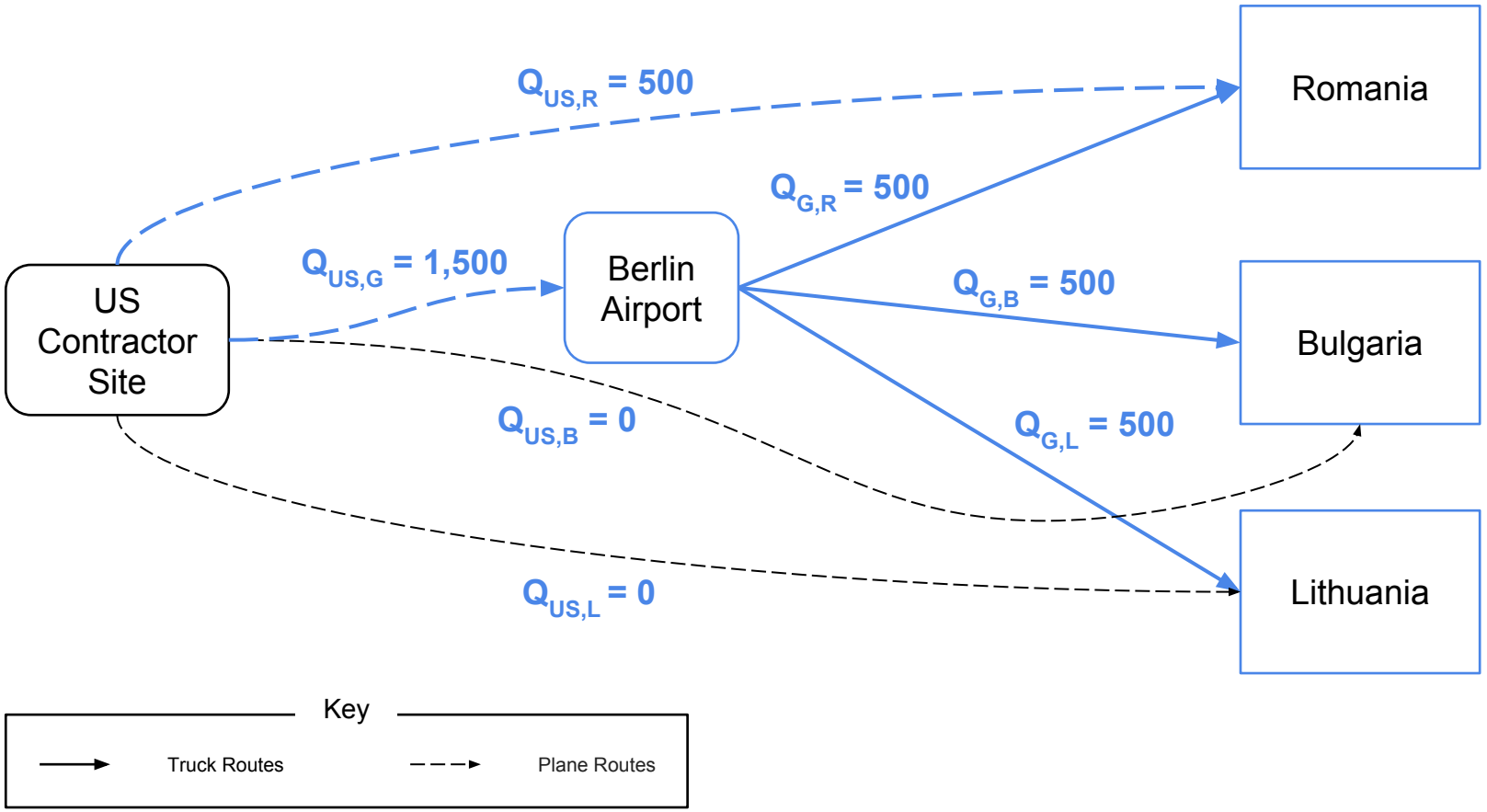
Simplified Illustration of Model - Optimal Solution

in '1000s



KNOWLEDGE FOR ACTION

Thank You

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Appendix 1

Transportation Costs

	Route	Type	Max Capacity	Fixed Cost	Unit Variable Cost	Route used	Quantity shipped	Total Cost
1	U.S. to Berlin	Plane	1,500	500	20	1	1,500	$30,500
2	U.S. to Romania	Plane	1,000	250	20	1	500	$10,250
3	U.S. to Bulgaria	Plane	1,000	250	20	0	0	$0
4	U.S. to Lithuania	Plane	1,000	250	20	0	0	$0
5	Berlin to Romania	Truck	1,000	200	40	1	500	$20,200
6	Berlin to Bulgaria	Truck	1,000	200	30	1	500	$15,200
7	Berlin to Lithuania	Truck	1,000	200	20	1	500	$10,200
								$86,350

Storage Costs

	Location	Demand	Initial Inventory	Max Capacity	Fixed Cost	Unit Variable Cost	Total Storage Cost
1	Berlin	0	0	5,000	250	50	$75,250
2	Romania	1,000	0	2,000	200	100	$50,200
3	Bulgaria	500	0	1,000	100	100	$0
4	Lithuania	500	0	1,000	100	100	$0
							$125,450

Objective Function	
Transportation Cost	$86,350
Storage Cost	$125,450
Overall Cost	**$211,800**

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Appendix 1 (continued)

1. Shipping Constraint

Route	Quantity shipped		Max. Capacity
U.S. to Berlin	1,500	<=	1,500
U.S. to Romania	500	<=	1,000
U.S. to Bulgaria	0	<=	0
U.S. to Lithuania	0	<=	0
Berlin to Romania	500	<=	1,000
Berlin to Bulgaria	500	<=	1,000
Berlin to Lithuania	500	<=	1,000

2. Max Storage Capacity

Warehouse	Initial Inventory	Quantity shipped in bulk	Quantity needing Storage		Max. Capacity
Berlin	0	1,500	1,500	<=	5,000
Romania	0	500	500	<=	2,000
Bulgaria	0	0	0	<=	0
Lithuania	0	0	0	<=	0

3. Demand Constraint

Location	Initial Inventory	Quantity shipped thru Plane	Quantity shipped thru Trucks	Total Units available		Demand	
Berlin	0	1,500	0	1,500	>=	1,500	(demand at Berlin is amount shipped on trucks)
Romania	0	500	500	1,000	>=	1,000	
Bulgaria	0	0	500	500	>=	500	
Lithuania	0	0	500	500	>=	500	

Appendix 2

Objective Cell (Min)

Cell	Name	Original Value	Final Value
$D$27	Overall Cost Initial Inventory	$1,800	$211,800

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$H$7	Plane Route used	1	1	Binary
$H$8	Plane Route used	1	1	Binary
$H$9	Plane Route used	0	0	Binary
$H$10	Plane Route used	0	0	Binary
$H$11	Truck Route used	1	1	Binary
$H$12	Truck Route used	1	1	Binary
$H$13	Truck Route used	1	1	Binary
$I$7	Plane Quantity shipped	0	1,500	Contin
$I$8	Plane Quantity shipped	0	500	Contin
$I$9	Plane Quantity shipped	0	0	Contin
$I$10	Plane Quantity shipped	0	0	Contin
$I$11	Truck Quantity shipped	0	500	Contin
$I$12	Truck Quantity shipped	0	500	Contin
$I$13	Truck Quantity shipped	0	500	Contin

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Appendix 2 (continued)

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$34	U.S. to Berlin Quantity shipped	1,500	$D$34<=$F$34	Binding	0
$D$35	U.S. to Romania Quantity shipped	500	$D$35<=$F$35	Not Binding	500
$D$36	U.S. to Bulgaria Quantity shipped	0	$D$36<=$F$36	Binding	0
$D$37	U.S. to Lithuania Quantity shipped	0	$D$37<=$F$37	Binding	0
$D$38	Berlin to Romania Quantity shipped	500	$D$38<=$F$38	Not Binding	500
$D$39	Berlin to Bulgaria Quantity shipped	500	$D$39<=$F$39	Not Binding	500
$D$40	Berlin to Lithuania Quantity shipped	500	$D$40<=$F$40	Not Binding	500
$E$45	Berlin Quantity needing Storage	1,500	$E$45<=$G$45	Not Binding	3500
$E$46	Romania Quantity needing Storage	500	$E$46<=$G$46	Not Binding	1500
$E$47	Bulgaria Quantity needing Storage	0	$E$47<=$G$47	Binding	0
$E$48	Lithuania Quantity needing Storage	0	$E$48<=$G$48	Binding	0
$F$53	Berlin Total Units available	1,500	$F$53>=$H$53	Binding	0
$F$54	Romania Total Units available	1,000	$F$54>=$H$54	Binding	0
$F$55	Bulgaria Total Units available	500	$F$55>=$H$55	Binding	0
$F$56	Lithuania Total Units available	500	$F$56>=$H$56	Binding	0
$H$7:$H$13=Binary					

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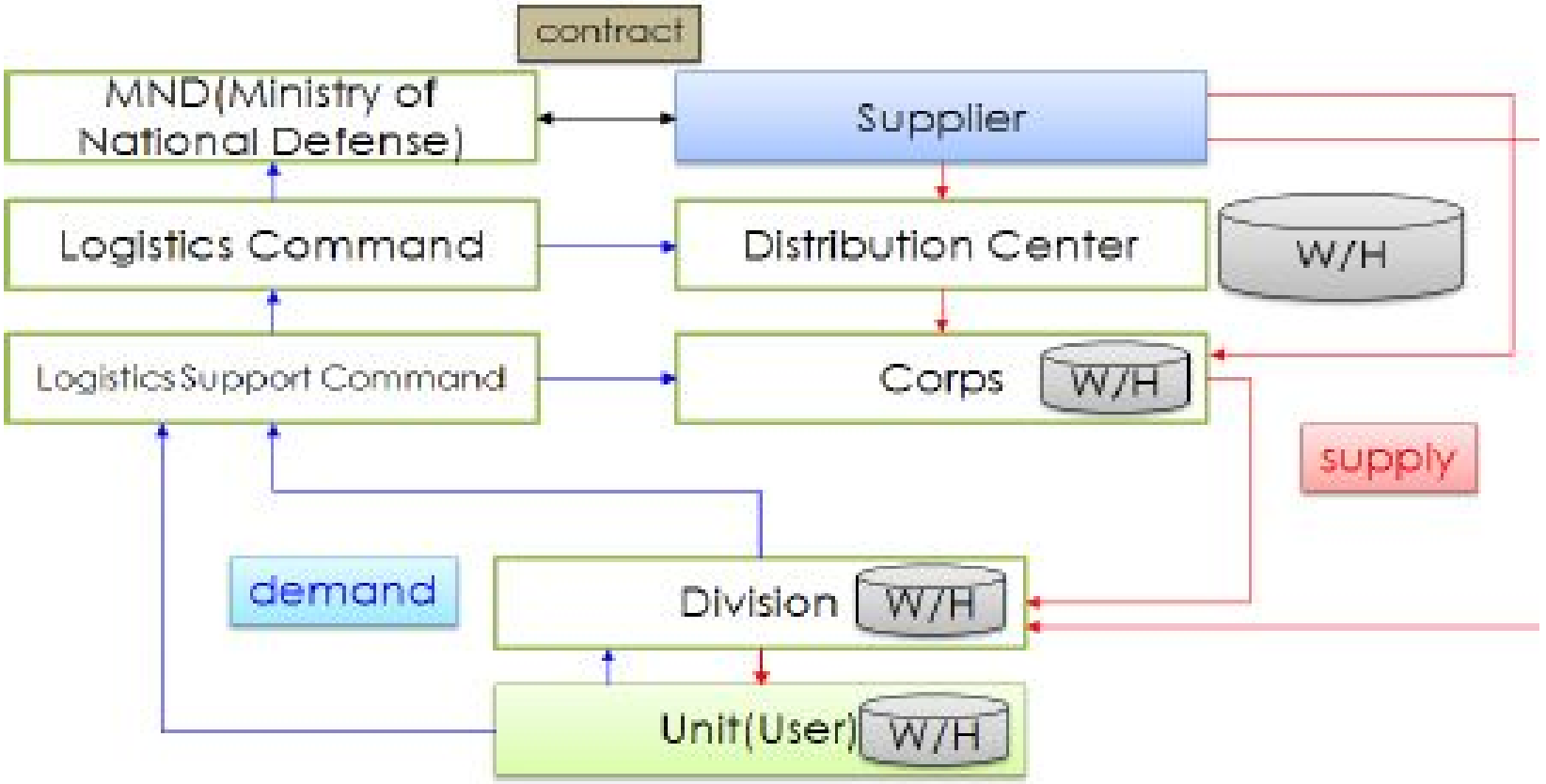
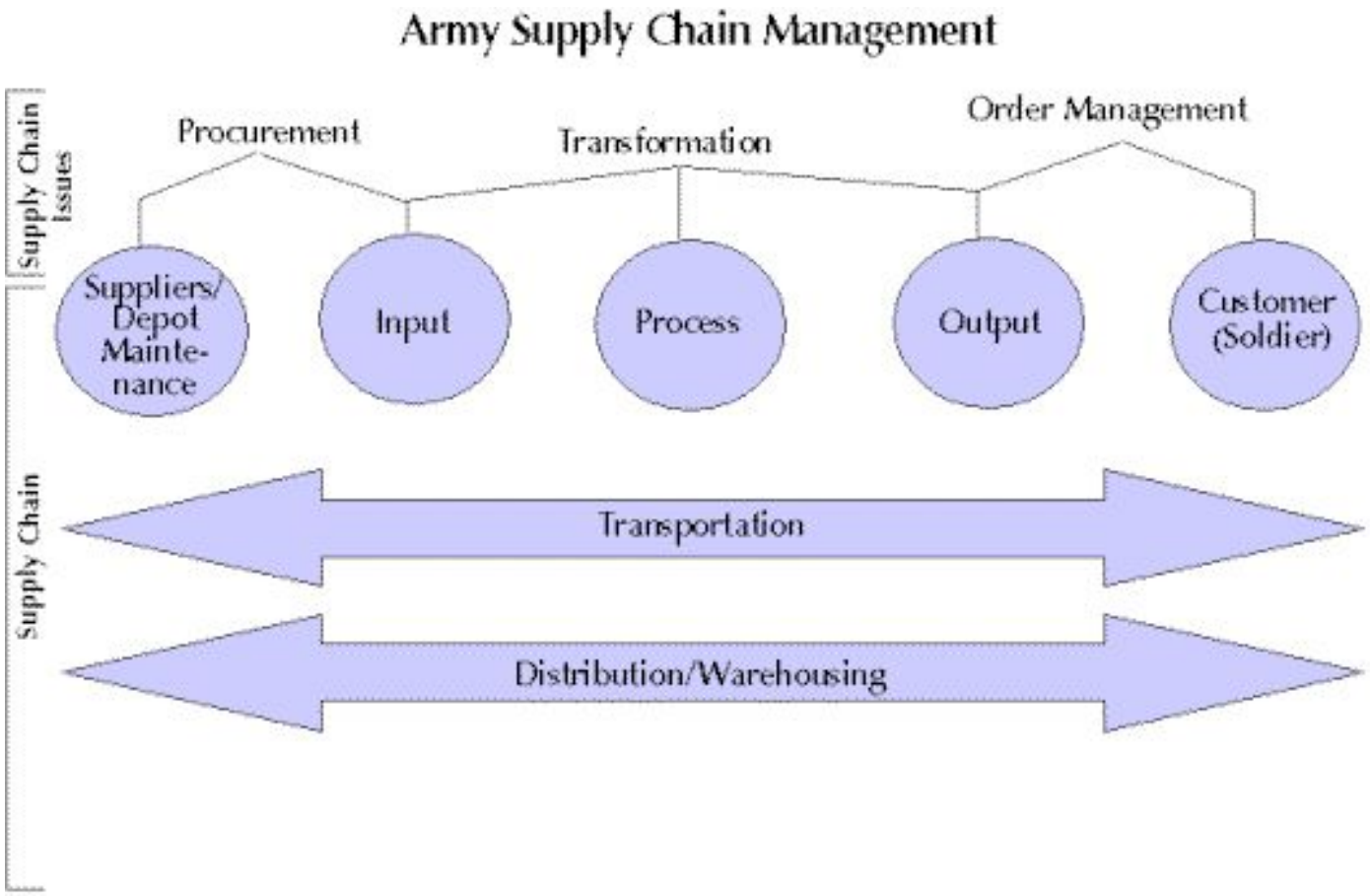
Appendix 3


contract
MND(Ministry of National Defense)
Supplier
Logistics Command
Distribution Center
W/H
Logistics Support Command
Corps
W/H
supply
demand
Division
W/H
Unit(User)
W/H

Appendix 4


Army Supply Chain Management
Supply Chain Issues
Procurement
Transformation
Order Management
Suppliers/ Depot Mainte-nance
Input
Process
Output
Customer (Soldier)
Supply Chain
Transportation
Distribution/Warehousing