Supply Chain Environmental Performance: Analysis & Optimization

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Motivation

- Sustainability is fast becoming the watch-word in both business and government
- Concerns about issues such as global warming are widespread -- no longer the exclusive domain of environmental activists
- We may be close to a tipping point in terms of awareness and support for environmental protection/performance

Motivation

- Consider, for example:
  - Strong environmental commitments of corporate giants such as Wal-Mart, HP, Nike, STMicroelectronics, Intel, etc.
  - California’s landmark legislation to cap greenhouse gas emissions
  - Sustainability focus at recent Oregon Leadership Summit

Intent of this work

- Respond to the need for quantitative tools to support sustainable business
- Directly address and optimize environmental performance of complex systems and networks
- Apply proven modeling and analysis techniques to create robust solutions

Why Supply Chains

- Supply chains are complex and interesting systems
- Supply chains are at the foundation of global commerce
- Sustainability of business depends on the sustainability of supply chains

Green Supply Chains

- Suppliers' manufacturing practices are certainly important, but there is more to it
- How we move goods is also going to be critical in a carbon-constrained world

Supply Chain Trends

- Supply chains now span long distances
- Require significant use of fossil fuels to transport goods to consumers
- Freight transport becoming a major source of CO_2 emissions

Supply Chain Trends

- Low inventory levels
  - Due to lean manufacturing and just-in-time deliveries
  - Frequent replenishment throughout the supply chain
  - Increase energy use and CO_2 emissions, depending on the product

[K. Venkat & W. Wakeland, “Is lean necessarily green?”, 50th Annual Meeting of the International Society for the Systems Sciences, 2006]

Freight Transport Trends

- Shippers increasingly value speed and reliability
- Favor truck and airfreight -- the most energy-intensive modes

Freight Transport Impacts

- Consumes nearly a quarter of all the petroleum worldwide
- Produces over 10 percent of the carbon emissions from fossil fuels

[Source: Scientific American, Sept. 2006]

Truck Emissions (US)

- Heavy trucks produce 16% of transport emissions
- Light trucks produce 19% of transport emissions
- Heavy & light trucks contribute nearly as much emissions as passenger cars

[* Source: Pew Center on Global Climate Change.]

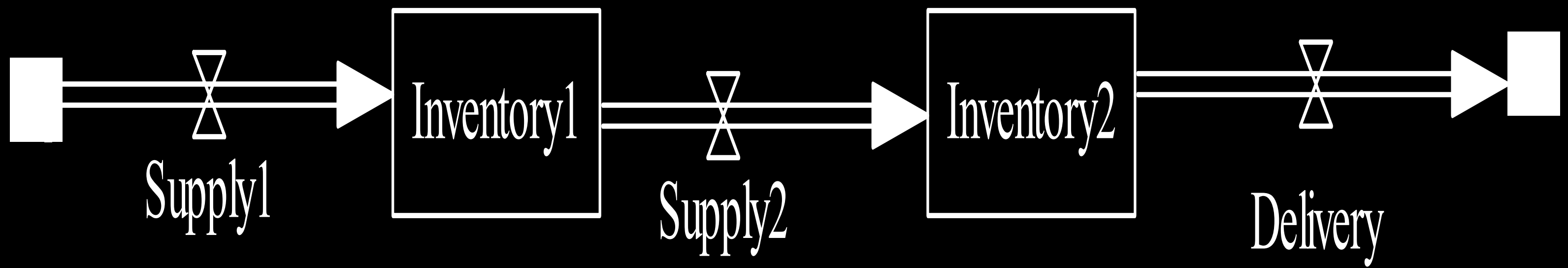
Heavy-duty Trucks

- Fuel costs are typically the second largest expense item
- Current efficiency improvements are mostly mechanical:
  - Reducing aerodynamic drag, reducing idling, using hybrid drive trains, etc.
- System-level optimizations could yield additional energy efficiencies

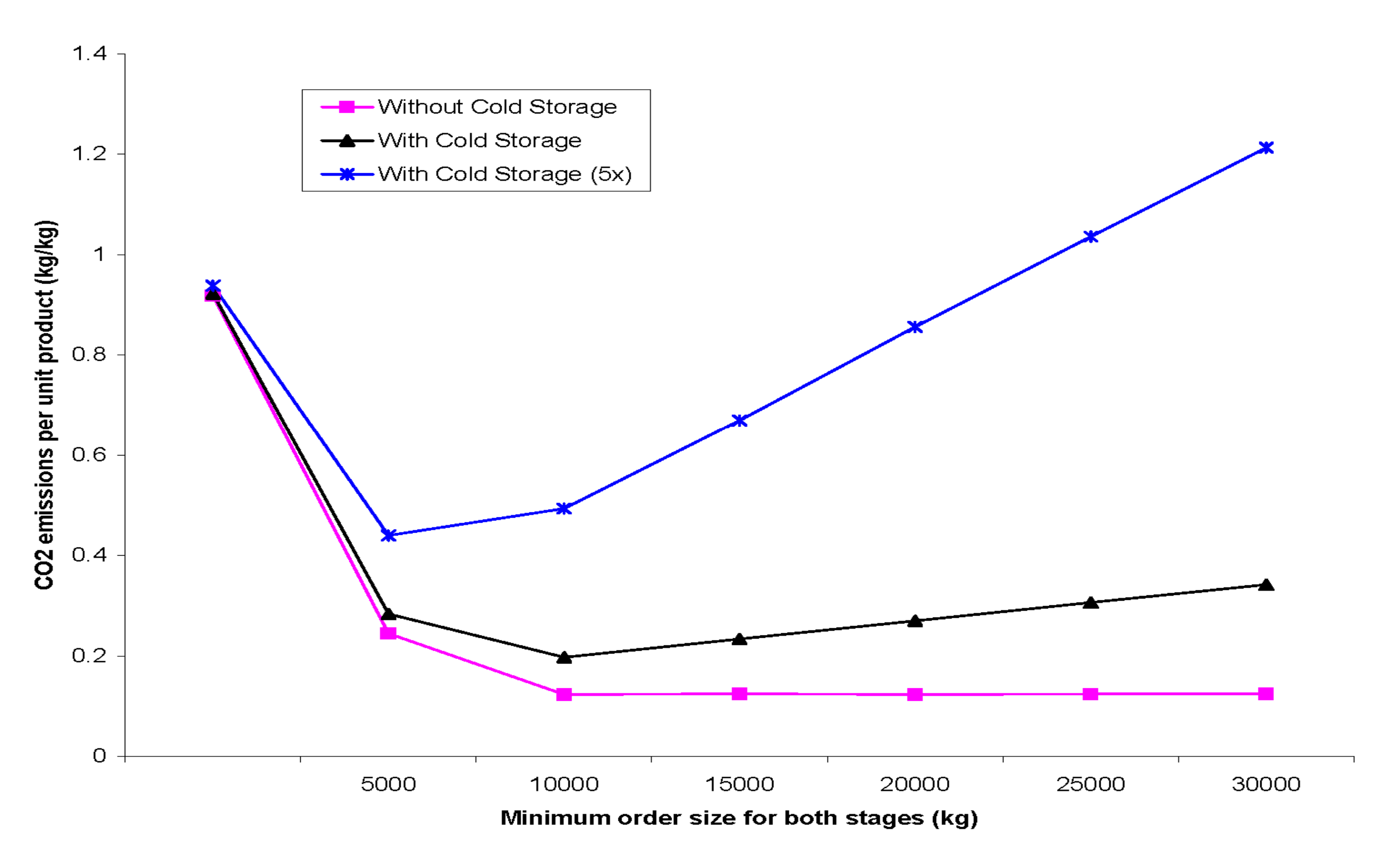
Reducing Emissions

- Reducing fuel use and emissions in freight transport by just 5% would save:
  - 32 million tons of carbon emissions, or 116 million tons of CO_2
  - 347 million barrels of petroleum per year

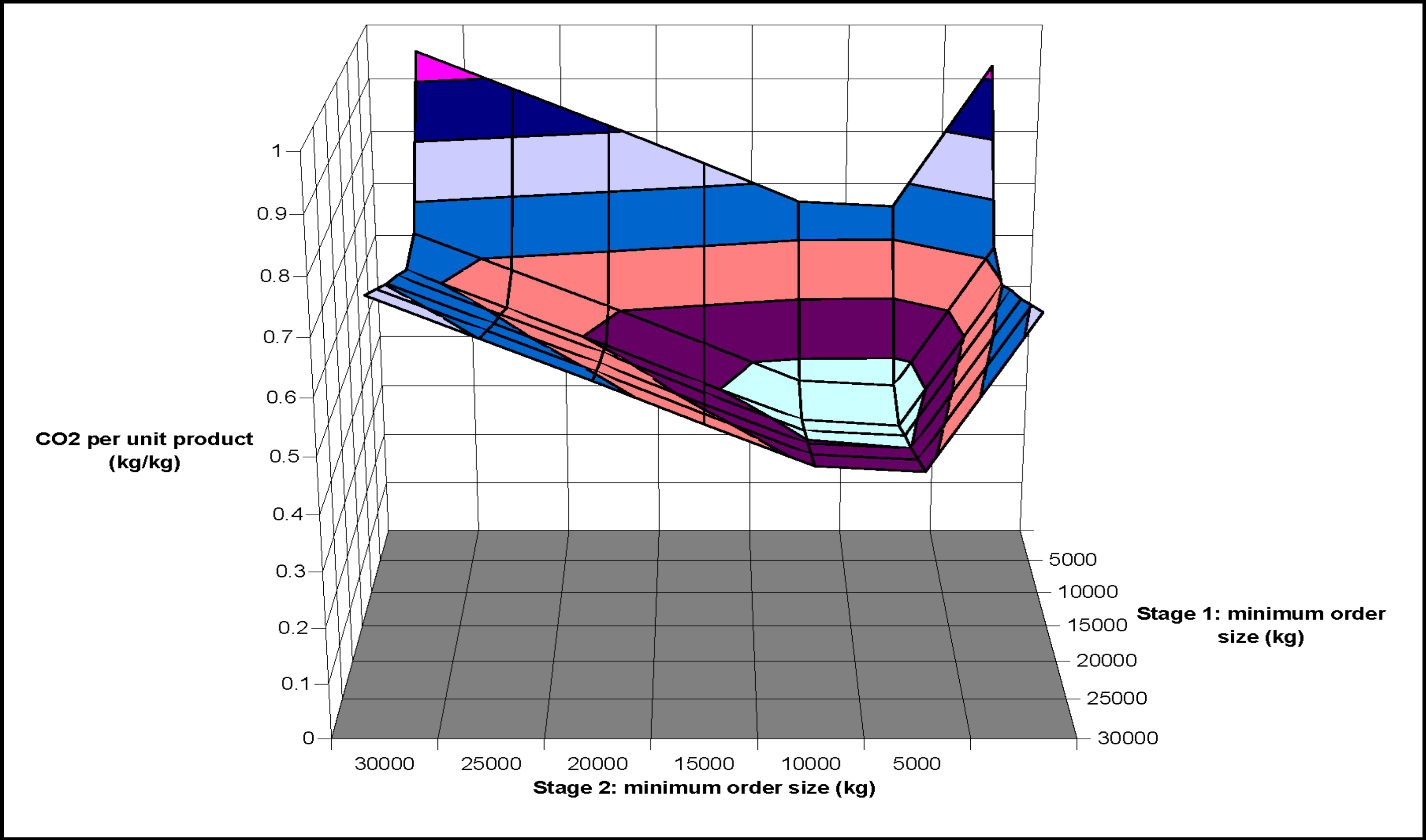
Generic Supply Chain



CO_2 Emissions: Lean supply chain



CO_2 Emissions: independent stages



Environmental Performance

- Environmental performance metrics:
  - Energy/fuel consumption
  - CO_2 emissions
  - Financial cost

Proposed Approach

- Direct analysis and improvement of environmental performance
- System-level view of the problem
- Offer a unique solution that complements other supply-chain, logistics and environmental analysis solutions

Opportunity

- Significant opportunities exist for improving the environmental performance of supply chains
  - Better performance at lower overall cost
  - Better performance without cost increase

Analysis Method

- System dynamics type of modeling for supply chain
  - Stocks and flows
- Static analysis algorithms
  - Find accurate bounds efficiently without long simulations
- Interactive tool presented to user
  - Hide computational details

Examples

- Manufacturing supply chain
- Frozen-food supply chain
- Cereal supply chain
- Dairy supply chain
- Printer supply chain

[For more details and data sources, see case studies at www.suryatech.com/ep]

Assumptions

- Fixed production batch sizes
- Full truck load shipments
  - Shipment sizes closely linked to transport modes
- Non-renewable energy sources
  - Energy use and CO_2 emissions highly correlated

Experiments

- Vary transport mode and shipment size on each transport link
  - Software computes changes in inventory levels throughout the supply chain
- Compute overall energy use, emissions and cost for each combination of transport modes and shipment sizes

Road Transport Modes

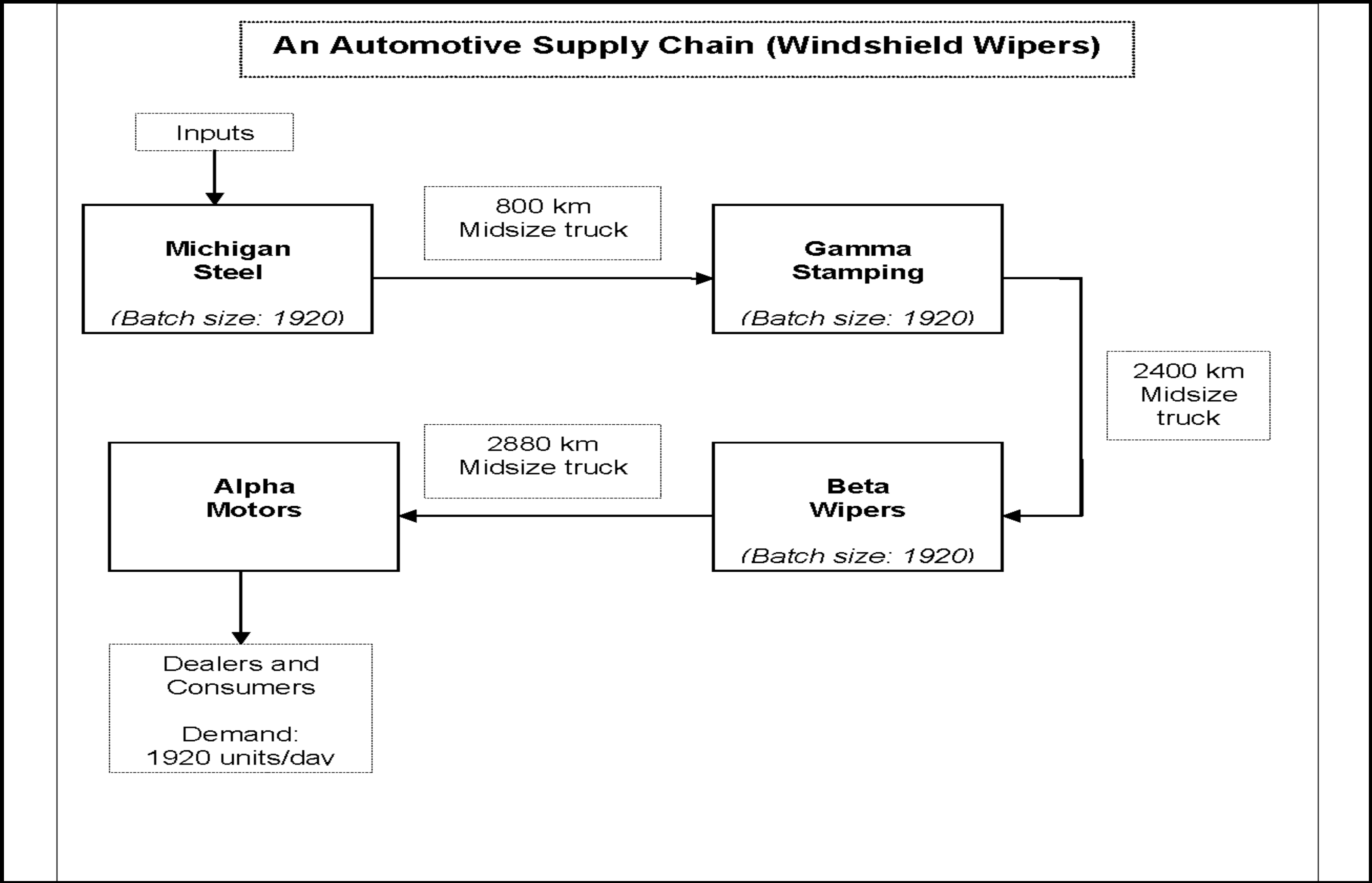
Transport Mode	Maximum Load (kg)	Fuel Type	CO_2 Emissions (g/ton-km)
Heavy-duty truck (H)	17300	Diesel	62
Midsize Truck (M)	6000	Diesel	122
Light Truck (L)	700	Gasoline	459

Optimization Space

- Number of solution points = M ^ L (M = # modes, L = # links)
- For a supply chain with 5 transport links and 3 possible modes at each link: 243 possible solution points in a 6-D space for each metric

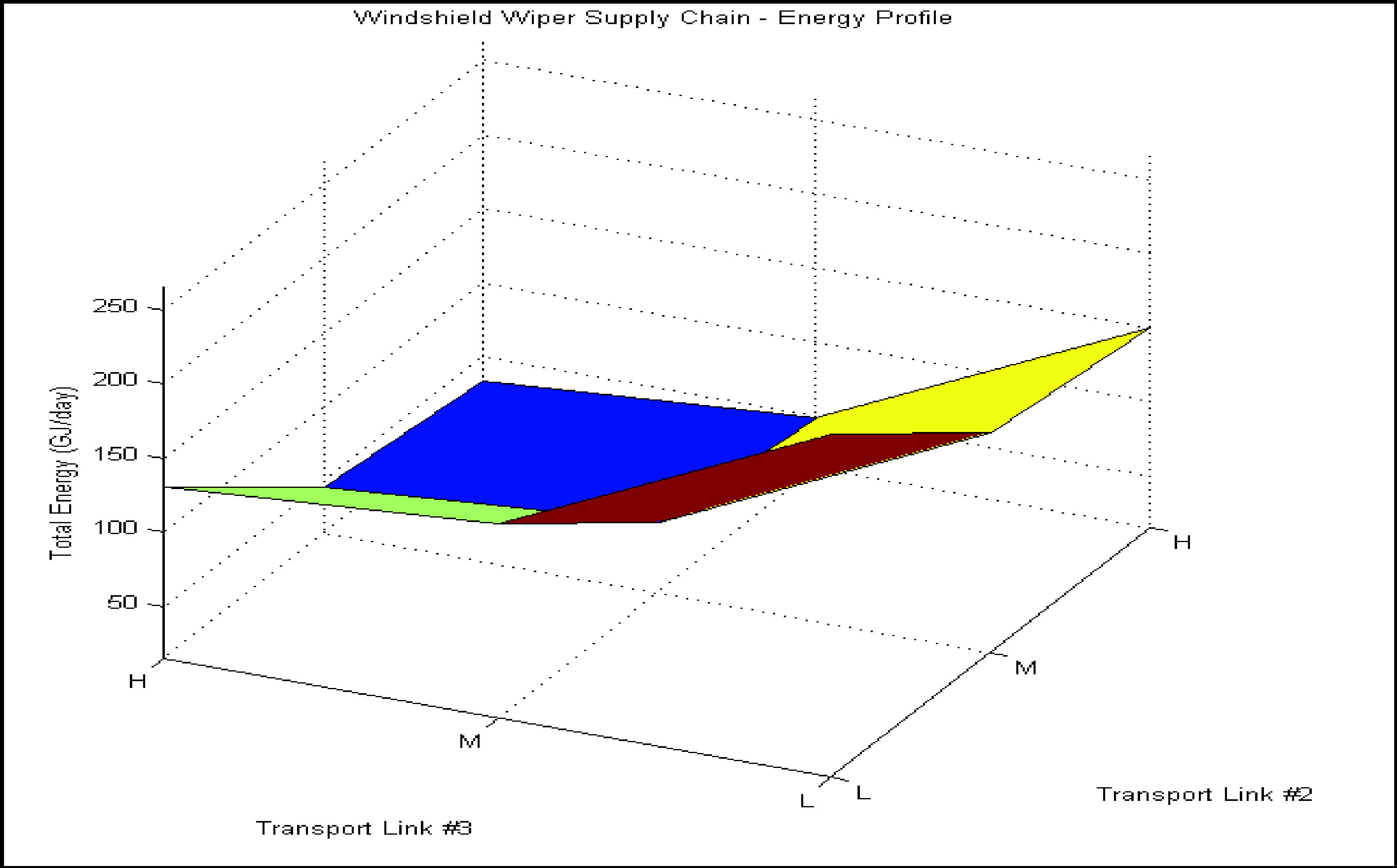
Visualization

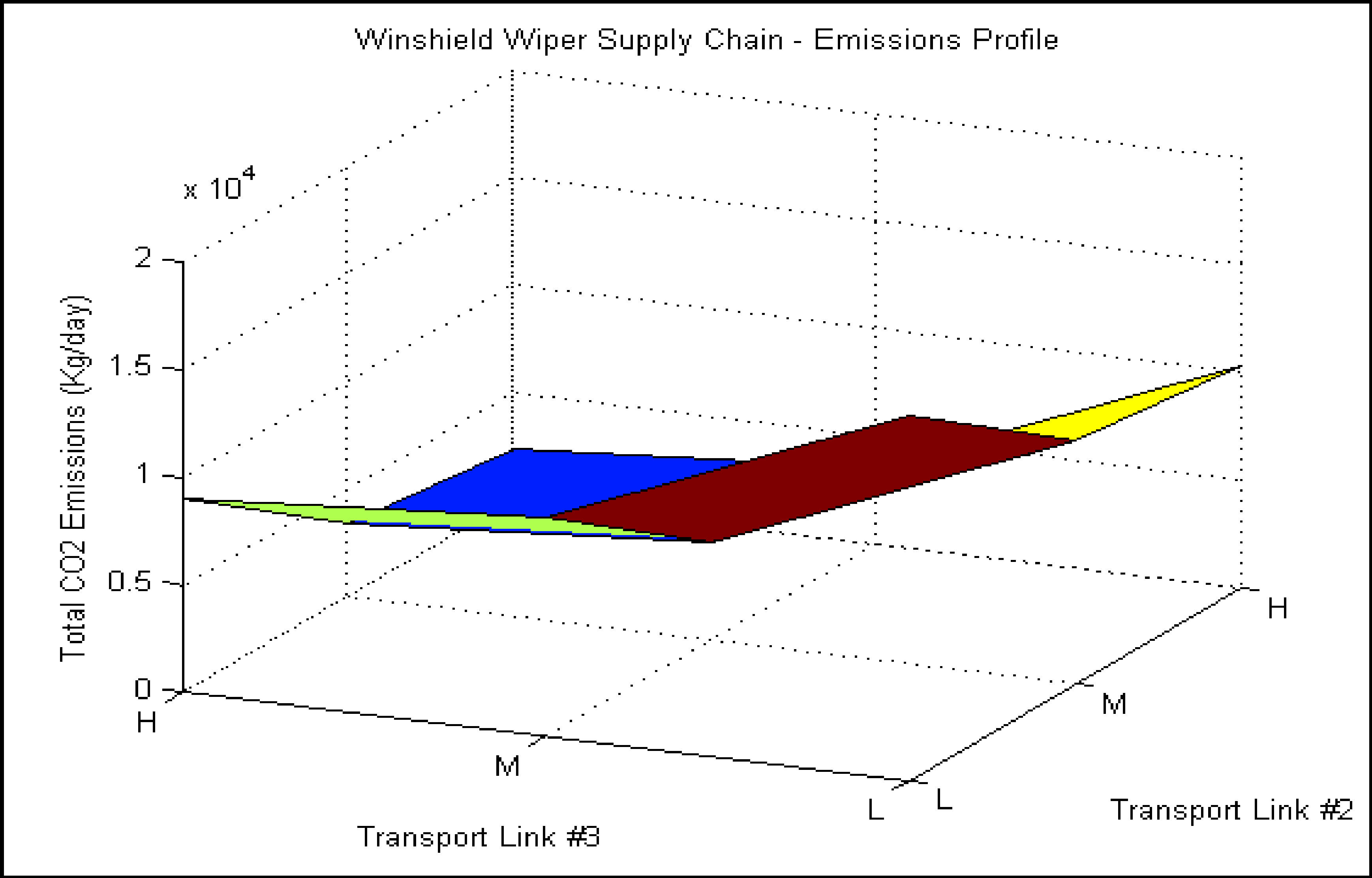
- For purposes of this presentation, we greatly reduce the degrees of freedom
- Transport modes and shipment sizes are varied at only <u>two</u> selected links (or groups of links) in each example
- Makes it possible to visualize a 3-D solution space

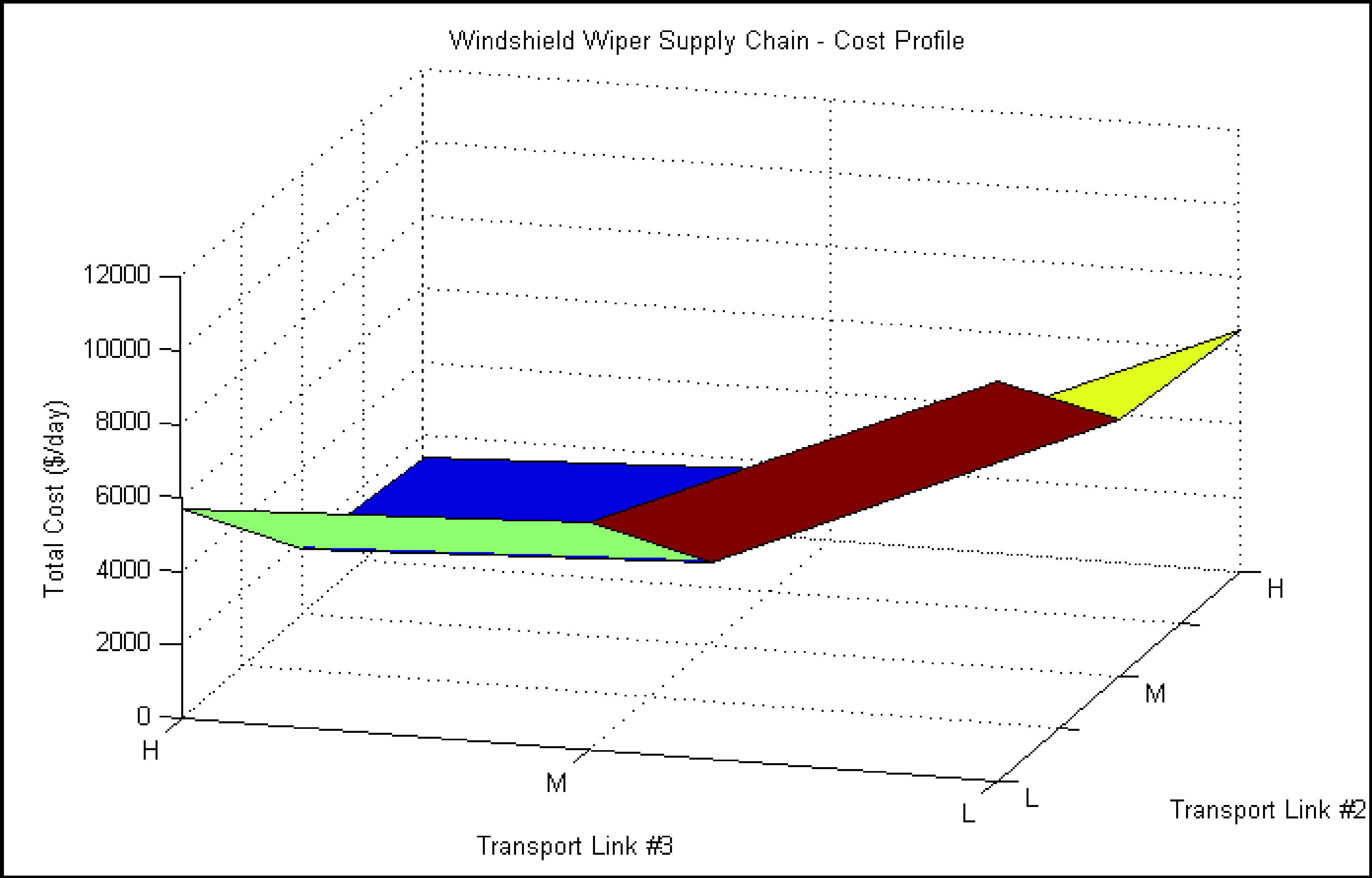

An Automotive Supply Chain (Windshield Wipers)
Inputs
Michigan Steel
(Batch size: 1920)
800 km
Midsize truck
Gamma Stamping
(Batch size: 1920)
2400 km
Midsize truck
Beta Wipers
(Batch size: 1920)
2880 km
Midsize truck
Alpha Motors
Dealers and Consumers
Demand:
1920 units/dav

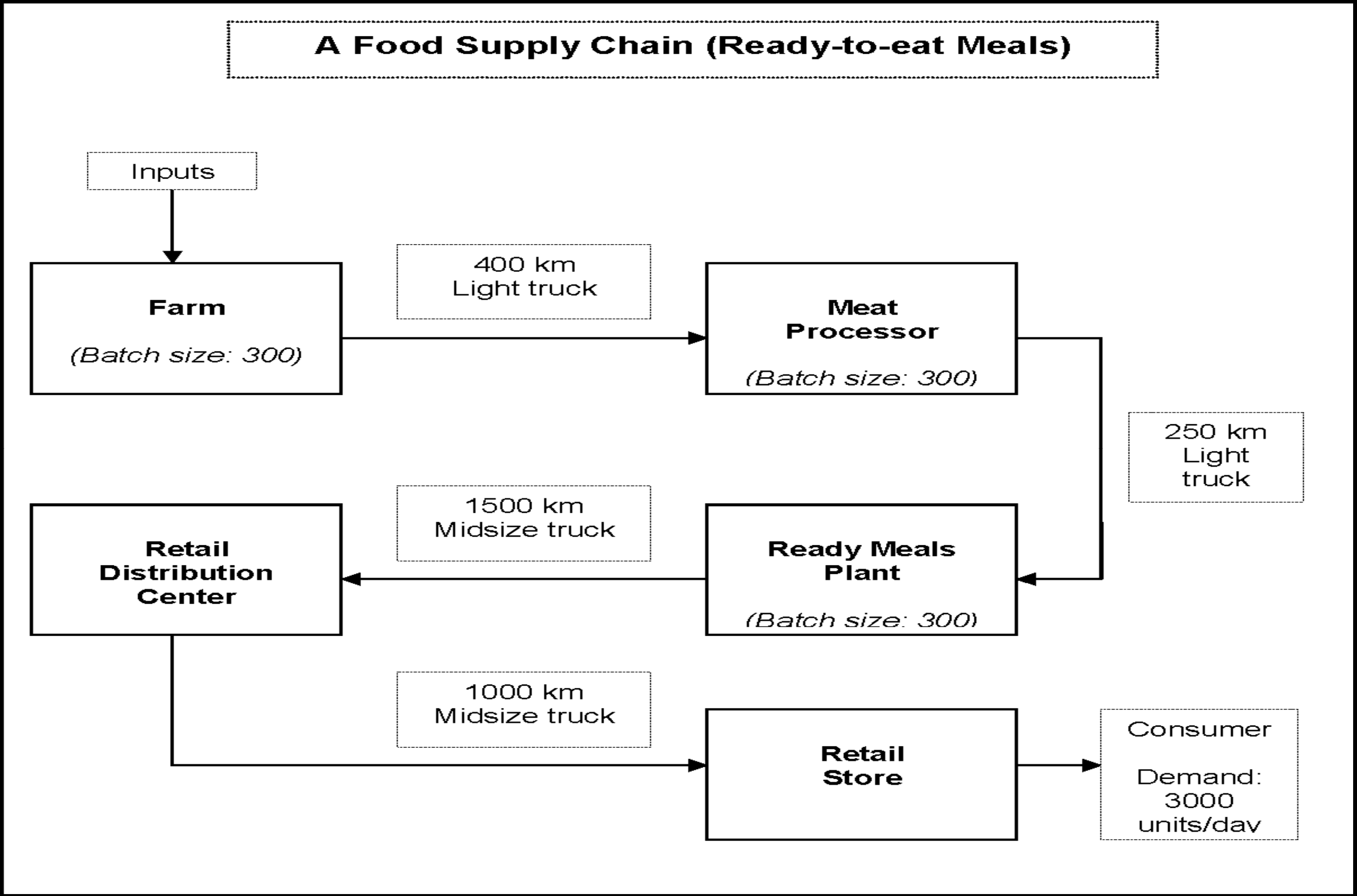
Node/Link	Mode	Energy/Fuel	Distance (Km)	Delivery Period (Days)	Batch Size or Ave. Inventory	Energy Used per Day (GJ)	Emissions Generated per Day (Kg-CO2)	Energy/Fuel Cost per Day ($)	Transportation Overhead Cost per Day ($)	Storage Overhead Cost per Day ($)	Total Cost per Day ($)
ToGammaStampingIn	MidsizeTruck (Transport)	Diesel	800.00	1.00	1920.00	8.22	604.70	175.51	120.00		295.51
ToBetaWipersIn	MidsizeTruck (Transport)	Diesel	2400.00	1.00	1920.00	24.66	1814.09	526.52	360.00		886.52
ToAlphaMotors	MidsizeTruck (Transport)	Diesel	2880.00	1.00	1920.00	29.60	2176.91	631.83	432.00		1063.83
GammaStampingIn	Warehouse (Storage)	None			0.00	0.00	0.00	0.00		0.00	0.00
GammaStampingOut	Warehouse (Storage)	None			0.00	0.00	0.00	0.00		0.00	0.00
BetaWipersIn	Warehouse (Storage)	None			0.00	0.00	0.00	0.00		0.00	0.00
BetaWipersOut	Warehouse (Storage)	None			0.00	0.00	0.00	0.00		0.00	0.00
GammaStamping	Production (Process)	None			1920.00	0.00	0.00	0.00			0.00
BetaWipers	Production (Process)	None			1920.00	0.00	0.00	0.00			0.00
<TOTAL>						62.48	4595.70	1333.85	912.00	0.00	2245.85

Node/Link	Mode	Energy/Fuel	Distance (Km)	Delivery Period (Days)	Batch Size or Ave. Inventory	Energy Used per Day (GJ)	Emissions Generated per Day (Kg-CO2)	Energy/Fuel Cost per Day ($)	Transportation Overhead Cost per Day ($)	Storage Overhead Cost per Day ($)	Total Cost per Day ($)
ToGammaStampingIn	HeavydutyTruck (Transport)	Diesel	800.00	3.00	5760.00	3.82	280.88	81.52	80.00		161.52
ToBetaWipersIn	HeavydutyTruck (Transport)	Diesel	2400.00	3.00	5760.00	11.46	842.65	244.57	240.00		484.57
ToAlphaMotors	HeavydutyTruck (Transport)	Diesel	2880.00	3.00	5760.00	13.75	1011.18	293.48	288.00		581.48
GammaStampingIn	Warehouse (Storage)	None			1920.00	0.00	0.00	0.00		8.45	8.45
GammaStampingOut	Warehouse (Storage)	None			1920.00	0.00	0.00	0.00		8.45	8.45
BetaWipersIn	Warehouse (Storage)	None			1920.00	0.00	0.00	0.00		8.45	8.45
BetaWipersOut	Warehouse (Storage)	None			1920.00	0.00	0.00	0.00		8.45	8.45
GammaStamping	Production (Process)	None			1920.00	0.00	0.00	0.00			0.00
BetaWipers	Production (Process)	None			1920.00	0.00	0.00	0.00			0.00
<TOTAL>						29.02	2134.71	619.58	608.00	33.79	1261.37


Windshield Wiper Supply Chain - Energy Profile
Total Energy (GJ/day)
250
200
150
100
50
H
M
L
Transport Link #3
L
M
H
Transport Link #2

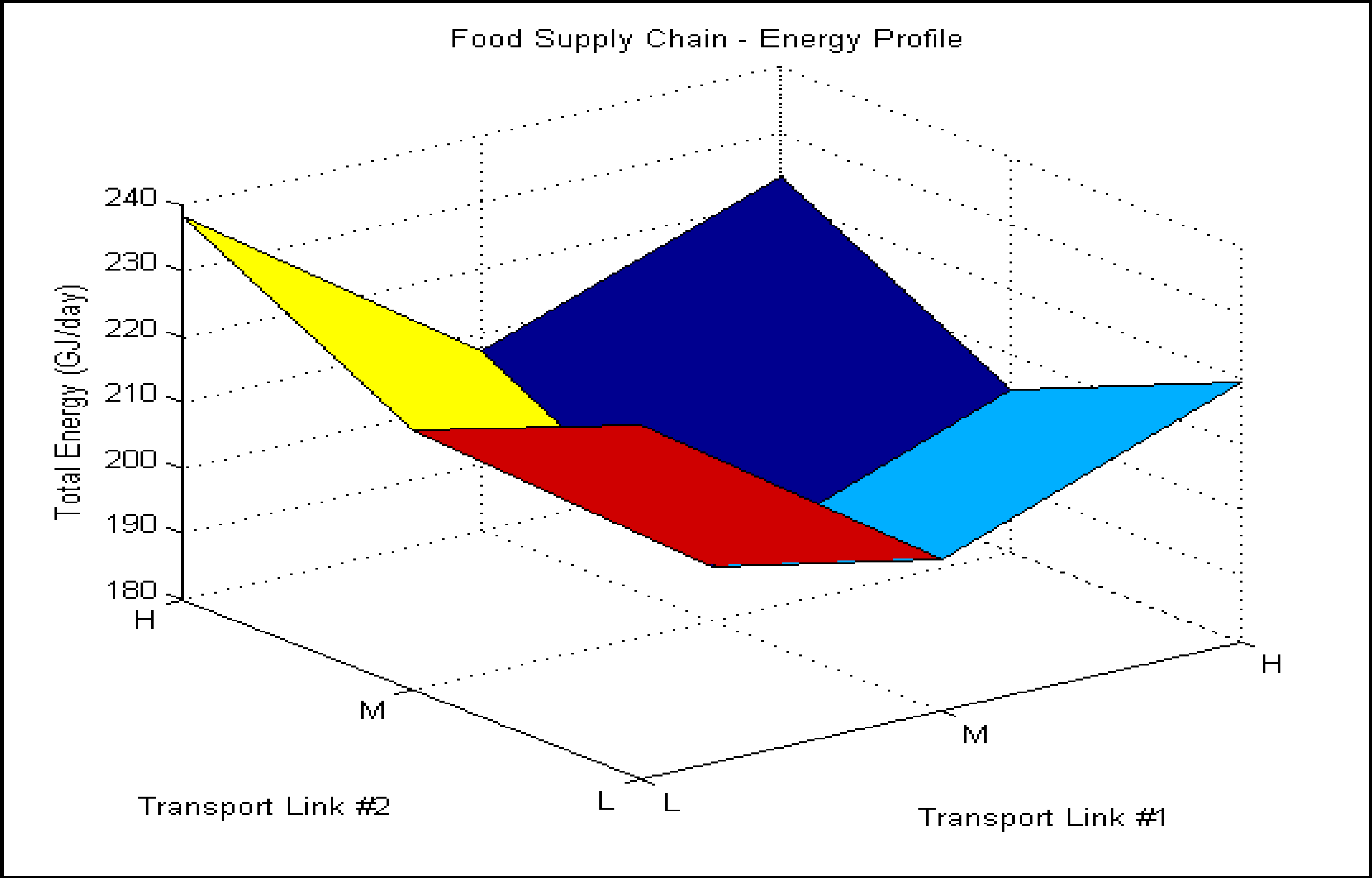

Winshield Wiper Supply Chain - Emissions Profile
x 10^4
2
1.5
1
0.5
0
Total CO2 Emissions (Kg/day)
H
M
L
Transport Link #3
L
M
H
Transport Link #2

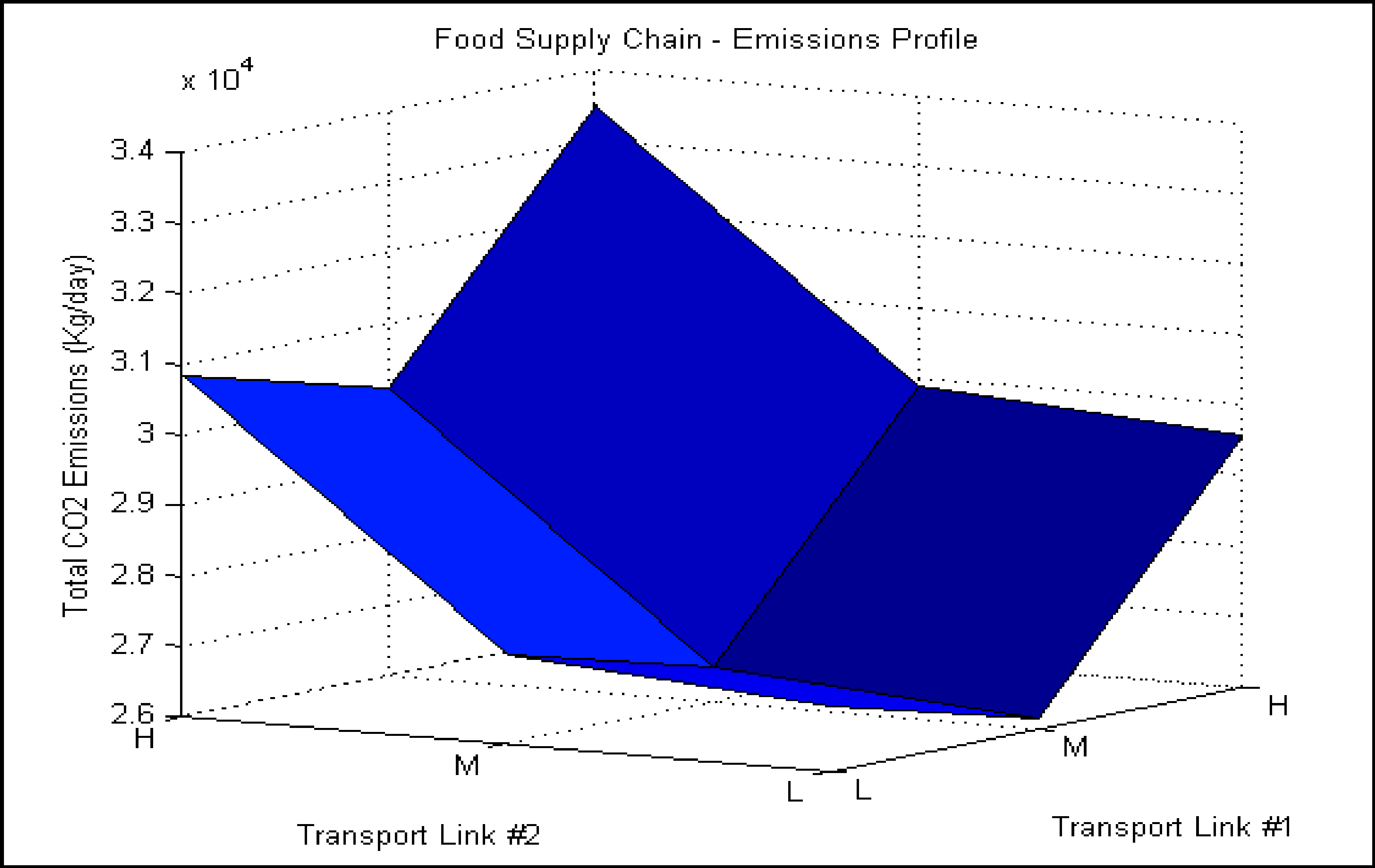

Windshield Wiper Supply Chain - Cost Profile
Total Cost ($/day)
12000
10000
8000
6000
4000
2000
0
H
M
L
Transport Link #3
L
M
H
Transport Link #2

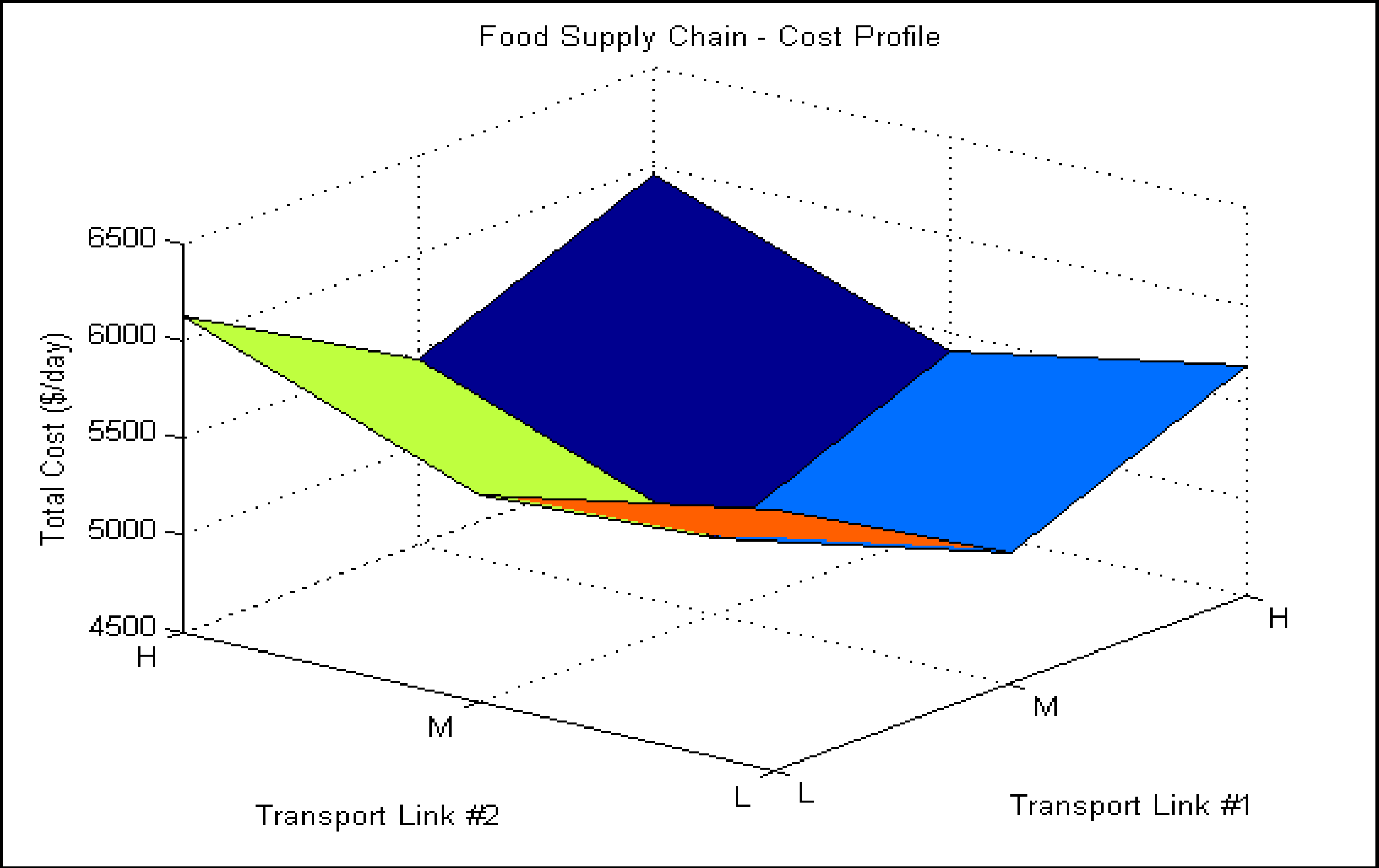

A Food Supply Chain (Ready-to-eat Meals)
Inputs
Farm
(Batch size: 300)
400 km
Light truck
Meat
Processor
(Batch size: 300)
250 km
Light
truck
Ready Meals
Plant
(Batch size: 300)
1500 km
Midsize truck
Retail
Distribution
Center
1000 km
Midsize truck
Retail
Store
Consumer
Demand:
3000
units/dav

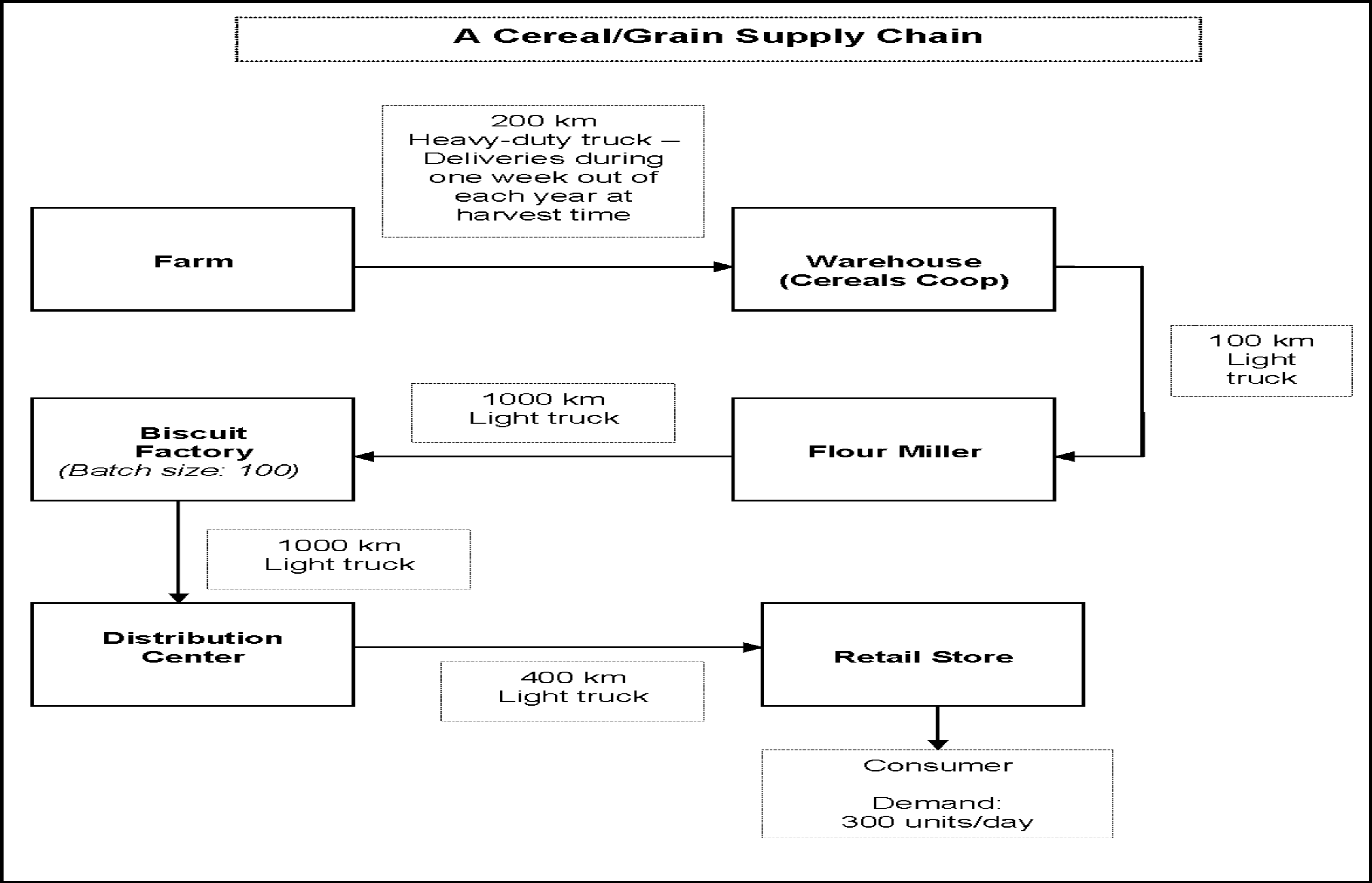
Node/Link	Mode	Energy/Fuel	Distance (Km)	Delivery Period (Days)	Batch Size or Ave. Inventory	Energy Used per Day (GJ)	Emissions Generated per Day (Kg-CO2)	Energy/Fuel Cost per Day ($)	Transportation Overhead Cost per Day ($)	Storage Overhead Cost per Day ($)	Total Cost per Day ($)
ToMeatPlantIn	LightTruck (Transport)	Gasoline	400.00	0.03	100.00	56.55	3856.48	1302.05	0.00		1302.05
ToReadyMealsPlantIn	LightTruck (Transport)	Gasoline	250.00	0.03	100.00	35.35	2410.30	813.78	0.00		813.78
ToRDC	MidsizeTruck (Transport)	Diesel	1500.00	0.33	1000.00	46.25	3401.42	987.23	0.00		987.23
ToRetailStore	MidsizeTruck (Transport)	Diesel	1000.00	0.33	1000.00	30.83	2267.62	658.15	0.00		658.15
FarmIn	StdStorage (Storage)	Electricity			100.00	0.00	0.00	0.00		0.44	0.44
FarmOut	ColdStorage (Storage)	Electricity			100.00	10.08	1703.18	280.00		0.44	280.44
MeatPlantIn	ColdStorage (Storage)	Electricity			100.00	10.08	1703.18	280.00		0.44	280.44
MeatPlantOut	ColdStorage (Storage)	Electricity			100.00	10.08	1703.18	280.00		0.44	280.44
ReadyMealsPlantIn	ColdStorage (Storage)	Electricity			100.00	10.08	1703.18	280.00		0.44	280.44
ReadyMealsPlantOut	ColdStorage (Storage)	Electricity			550.00	16.56	2798.09	460.00		2.42	462.42
RDC	ColdStorage (Storage)	Electricity			0.00	8.64	1459.87	240.00		0.00	240.00
RetailStore	ColdStorage (Storage)	Electricity			450.00	15.12	2554.78	420.00		1.98	421.98
Farm	GenericProcess (Process)	None			300.00	0.00	0.00	0.00			0.00
MeatPlant	GenericProcess (Process)	None			300.00	0.00	0.00	0.00			0.00
ReadyMealsPlant	GenericProcess (Process)	None			300.00	0.00	0.00	0.00			0.00
<TOTAL>						249.61	25561.29	6001.21	0.00	6.60	6007.81

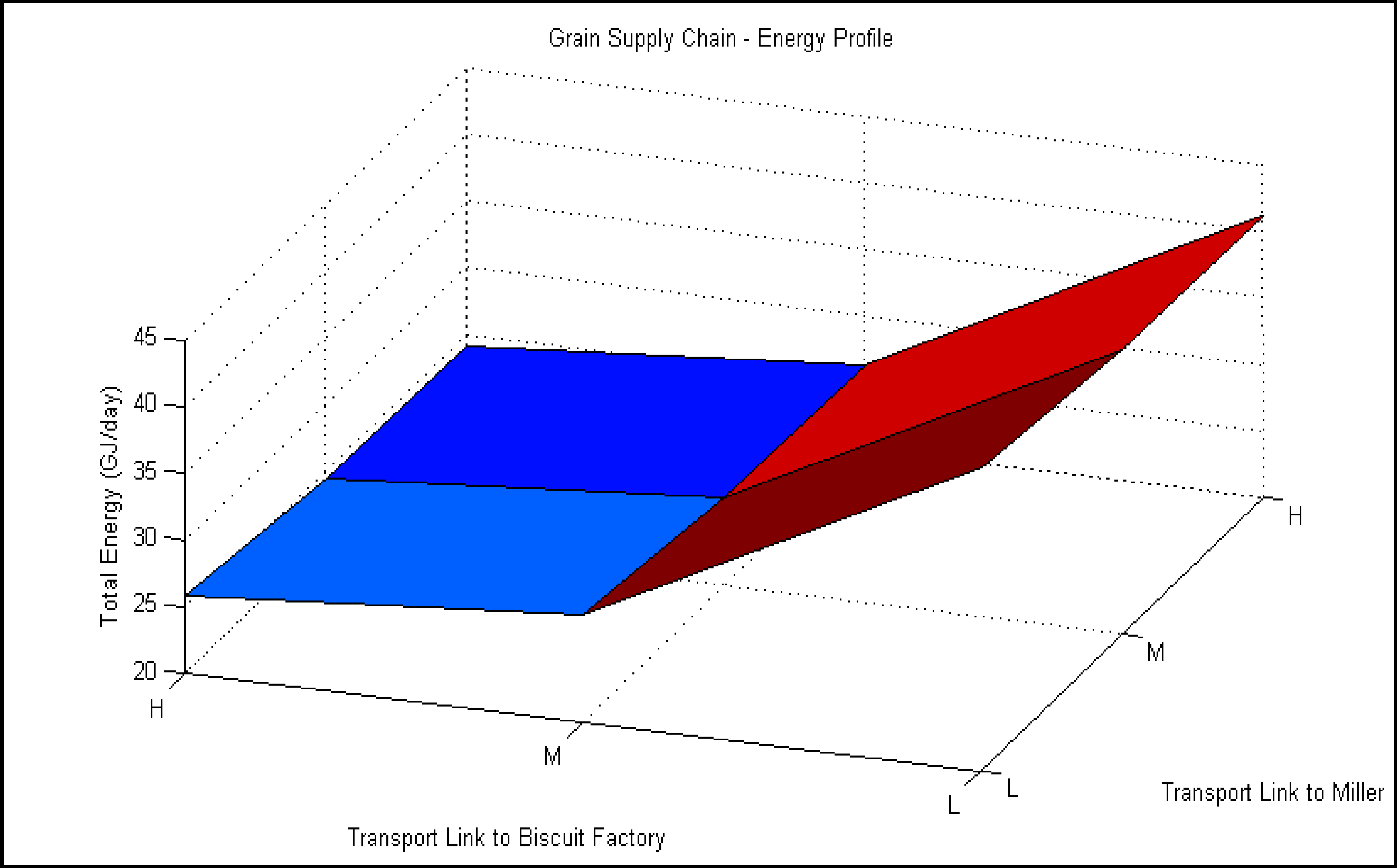
Node/Link	Mode	Energy/Fuel	Distance (Km)	Delivery Period (Days)	Batch Size or Ave. Inventory	Energy Used per Day (GJ)	Emissions Generated per Day (Kg-CO2)	Energy/Fuel Cost per Day ($)	Transportation Overhead Cost per Day ($)	Storage Overhead Cost per Day ($)	Total Cost per Day ($)
ToMeatPlantIn	MidsizeTruck (Transport)	Diesel	400.00	0.33	1000.00	12.33	907.05	263.26	0.00		263.26
ToReadyMealsPlantIn	MidsizeTruck (Transport)	Diesel	250.00	0.33	1000.00	7.71	566.90	164.54	0.00		164.54
ToRDC	HeavydutyTruck (Transport)	Diesel	1500.00	1.00	3000.00	21.48	1579.96	458.57	0.00		458.57
ToRetailStore	HeavydutyTruck (Transport)	Diesel	1000.00	1.00	3000.00	14.32	1053.31	305.71	0.00		305.71
FarmIn	StdStorage (Storage)	Electricity			100.00	0.00	0.00	0.00		0.44	0.44
FarmOut	ColdStorage (Storage)	Electricity			550.00	16.56	2798.09	460.00		2.42	462.42
MeatPlantIn	ColdStorage (Storage)	Electricity			550.00	16.56	2798.09	460.00		2.42	462.42
MeatPlantOut	ColdStorage (Storage)	Electricity			550.00	16.56	2798.09	460.00		2.42	462.42
ReadyMealsPlantIn	ColdStorage (Storage)	Electricity			550.00	16.56	2798.09	460.00		2.42	462.42
ReadyMealsPlantOut	ColdStorage (Storage)	Electricity			1350.00	28.08	4744.58	780.00		5.94	785.94
RDC	ColdStorage (Storage)	Electricity			0.00	8.64	1459.87	240.00		0.00	240.00
RetailStore	ColdStorage (Storage)	Electricity			1450.00	29.52	4987.90	820.00		6.38	826.38
Farm	GenericProcess (Process)	None			300.00	0.00	0.00	0.00			0.00
MeatPlant	GenericProcess (Process)	None			300.00	0.00	0.00	0.00			0.00
ReadyMealsPlant	GenericProcess (Process)	None			300.00	0.00	0.00	0.00			0.00
<TOTAL>						188.32	26491.93	4872.08	0.00	22.44	4894.52

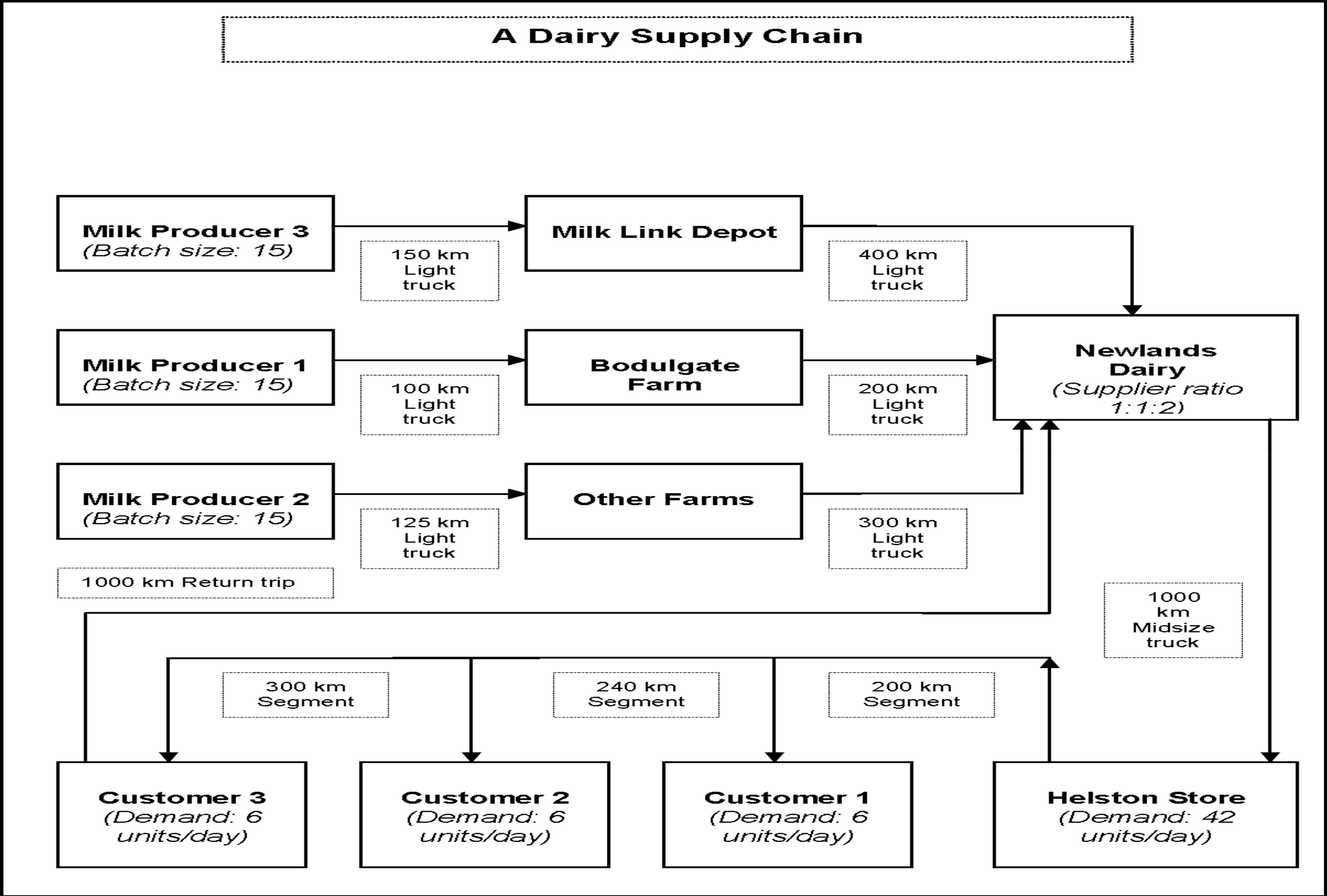

Food Supply Chain - Energy Profile
Total Energy (GJ/day)
240
230
220
210
200
190
180
H
M
L
Transport Link #2
L
M
H
Transport Link #1

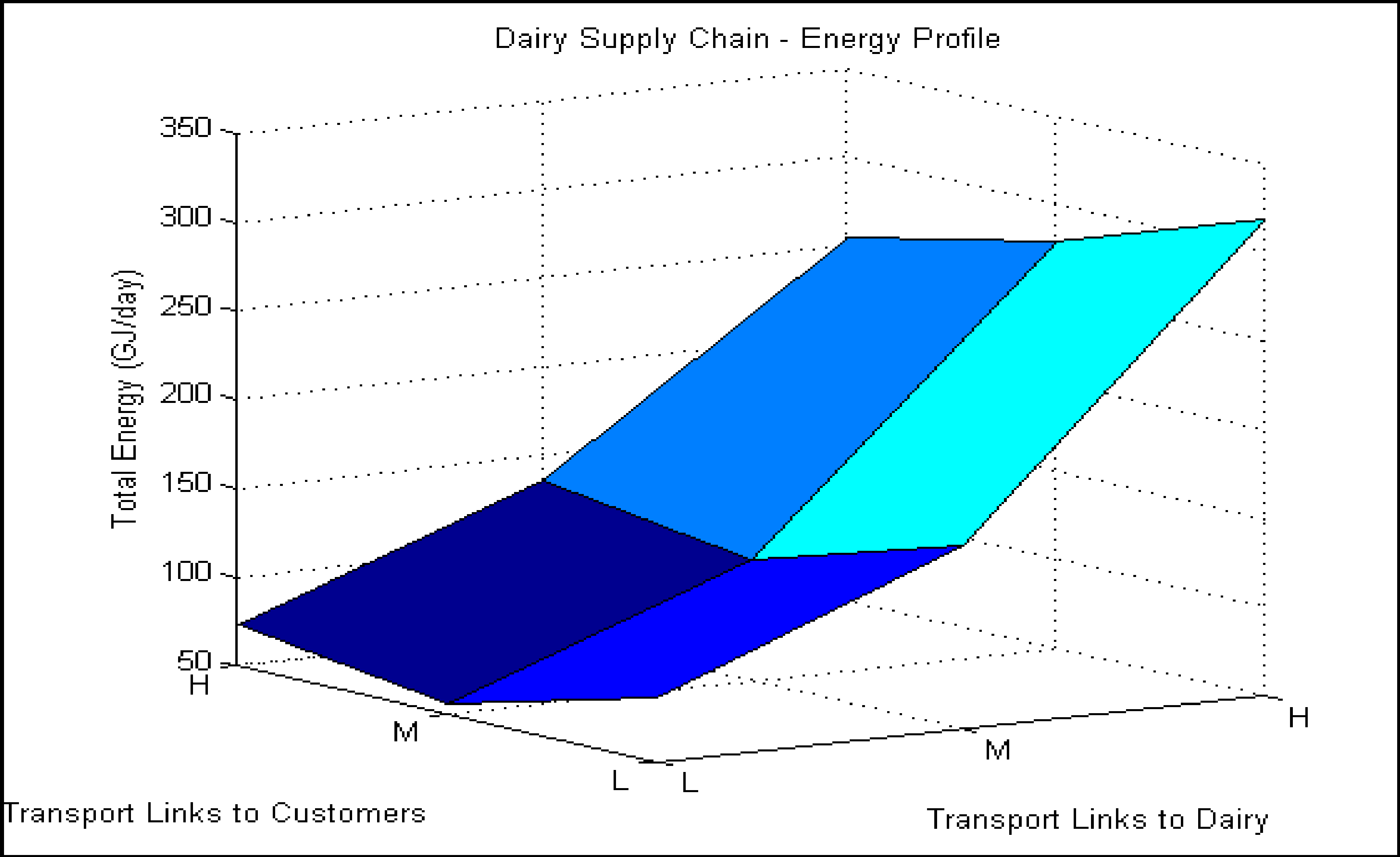

Food Supply Chain - Emissions Profile
x 10^4
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
Total CO2 Emissions (Kg/day)
H
M
L
Transport Link #2
L
M
H
Transport Link #1

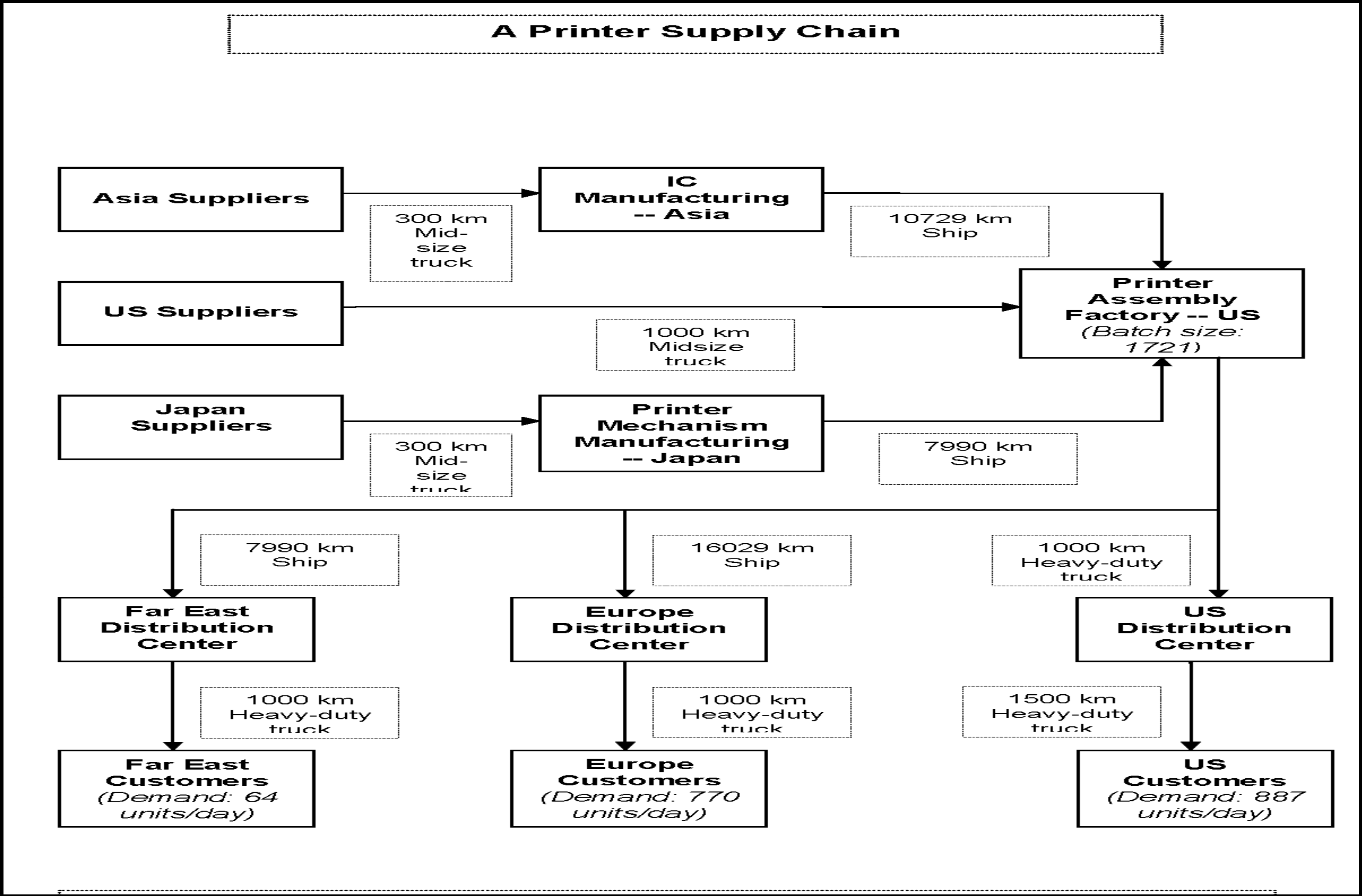

Food Supply Chain - Cost Profile
Total Cost ($/day)
6500
6000
5500
5000
4500
H
M
L
Transport Link #2
L
M
H
Transport Link #1

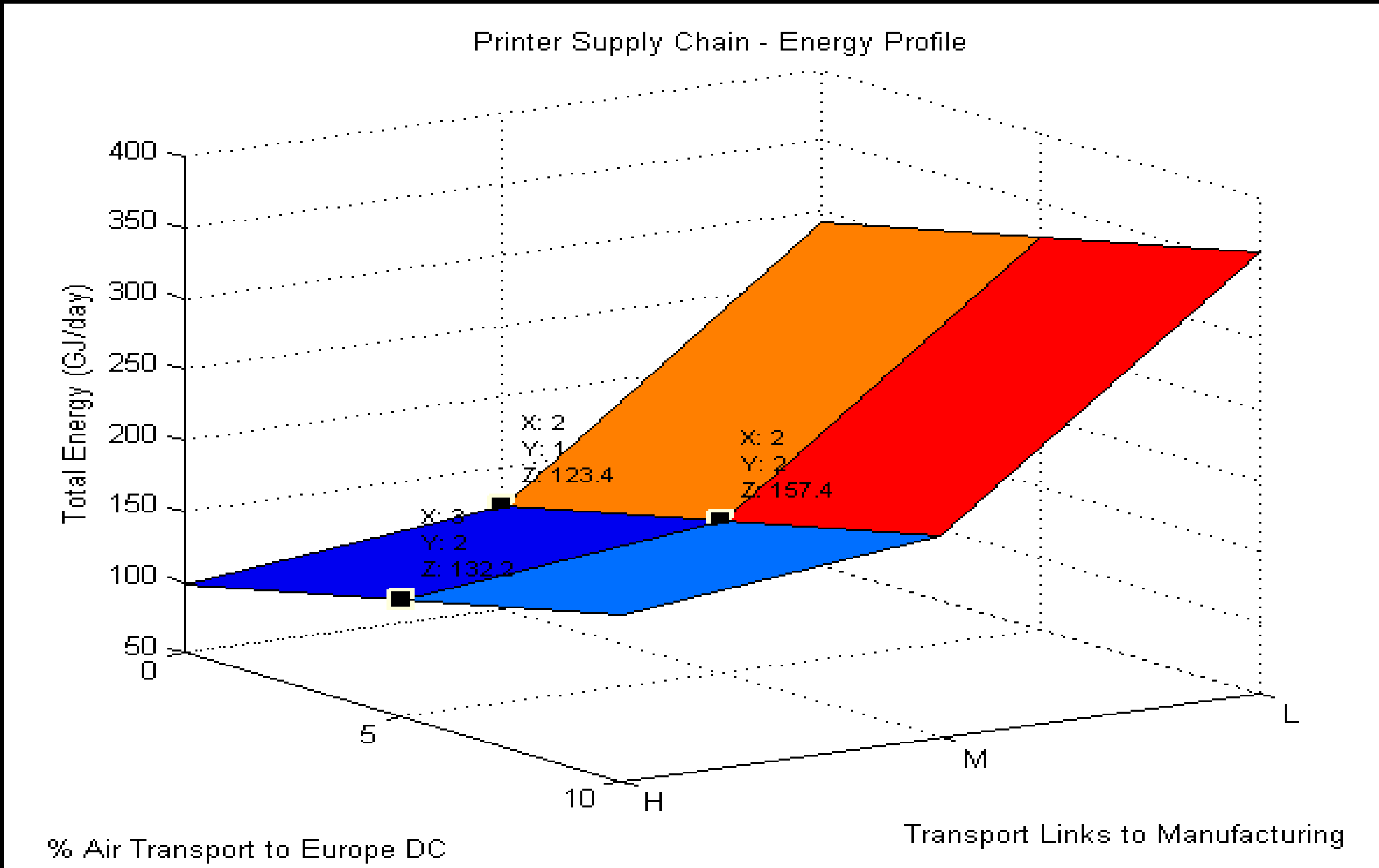

A Cereal/Grain Supply Chain
200 km
Heavy-duty truck –
Deliveries during
one week out of
each year at
harvest time
Farm
Warehouse
(Cereals Coop)
100 km
Light
truck
1000 km
Light truck
Biscuit
Factory
(Batch size: 100)
Flour Miller
1000 km
Light truck
Distribution
Center
Retail Store
400 km
Light truck
Consumer
Demand:
300 units/day


Grain Supply Chain - Energy Profile
Total Energy (GJ/day)
45
40
35
30
25
20
H
M
L
Transport Link to Biscuit Factory
H
M
L
Transport Link to Miller


A Dairy Supply Chain
Milk Producer 3
(Batch size: 15)
150 km
Light
truck
Milk Link Depot
400 km
Light
truck
Milk Producer 1
(Batch size: 15)
100 km
Light
truck
Bodulgate
Farm
200 km
Light
truck
Newlands
Dairy
(Supplier ratio
1:1:2)
Milk Producer 2
(Batch size: 15)
125 km
Light
truck
Other Farms
300 km
Light
truck
1000 km Return trip
1000
km
Midsize
truck
300 km
Segment
240 km
Segment
200 km
Segment
Customer 3
(Demand: 6
units/day)
Customer 2
(Demand: 6
units/day)
Customer 1
(Demand: 6
units/day)
Helston Store
(Demand: 42
units/day)


Dairy Supply Chain - Energy Profile
Total Energy (GJ/day)
350
300
250
200
150
100
50
H
M
L
L
M
H
Transport Links to Customers
Transport Links to Dairy


A Printer Supply Chain
Asia Suppliers
300 km Mid-size truck
IC Manufacturing -- Asia
10729 km Ship
US Suppliers
1000 km Midsize truck
Printer Assembly Factory -- US (Batch size: 1721)
Japan Suppliers
300 km Mid-size truck
Printer Mechanism Manufacturing -- Japan
7990 km Ship
7990 km Ship
16029 km Ship
1000 km Heavy-duty truck
Far East Distribution Center
Europe Distribution Center
US Distribution Center
1000 km Heavy-duty truck
1000 km Heavy-duty truck
1500 km Heavy-duty truck
Far East Customers (Demand: 64 units/day)
Europe Customers (Demand: 770 units/day)
US Customers (Demand: 887 units/day)


Printer Supply Chain - Energy Profile
Total Energy (GJ/day)
400
350
300
250
200
150
100
50
0
X: 2
Y: 1
Z: 123.4
X: 2
Y: 2
Z: 157.4
X: 3
Y: 2
Z: 132.2
5
10
H
M
L
% Air Transport to Europe DC
Transport Links to Manufacturing

Optimality Considerations

- When storage doesn’t require high energy use, larger shipment sizes and more energy-efficient transport modes are preferable
- Shipment size constrained by inventory-holding costs

Optimality Considerations

- When storage is energy-intensive, optimal shipment sizes and transport modes will vary depending on the product and supply chain
- Intermediate shipment sizes may work in many cases

Optimality Considerations

- Fixed production schedule (such as daily production), combined with refrigeration requirements, may require shipment sizes aligned with the production batch sizes

Current Application Areas

- Achieving overall cost savings from reduced energy use in supply chains
- Meeting voluntary or mandatory greenhouse gas emission targets
- Emission calculations for use in offsetting carbon footprints
- Detailed corporate reporting of energy use and emissions

Conclusion

- Supply chains are highly suited for rigorous analysis and optimization of environmental performance
- Approach outlined here could help with the transition to sustainable business

More Info

- More information available at www.suryatech.com/ep

Other Quantitative Tools

- Sustainable business requires several other quantitative tools, including:
  - Simplified life-cycle analysis (LCA) for both businesses and consumers
  - Mapping and analyzing material and energy flows: industrial metabolism, regional metabolism, etc.
- Transportation plays a central role