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INF170
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Report – Mandatory Assignment: Supply chain network design

Task 1

Model

Sets:

$SSet: Set\ of\ suppliers\ (counties).$

$PSet: Set\ of\ potential\ plants\ (biorefineries).$

Parameters:

$Supply_s: Supply\ of\ biomass\ from\ supplier\ s\ (tonne).$

$Yield = 232: Conversion\ yield\ of\ bioethanol\ (liters\ per\ tonne\ of\ biomass).$

$PlantCap = 152\ 063\ 705: Annual\ conversion\ capacity\ for\ each\ plant\ (liters).$

$Demand = 500\ 000\ 000: Total\ bioethanol\ demand\ (production\ target)\ (liters).$

$InvCost_p: Investment\ cost\ to\ maintain\ a\ plant\ at\ location\ p\ (\$).$

$TransCost_{sp}: Transportation\ cost\ from\ supplier\ s\ to\ plant\ p\ \left(\frac{\$}{tonne}\ per\ km\right).$

$Dist_{sp}: Distance\ from\ supplier\ s\ to\ plant\ p\ (km).$

$LoadCost = 10000: Combined\ loading\ and\ unloading\ cost\ for\ each\ trip\ (\$).$

$TruckCap = 500: Capacity\ of\ truck\ (tonne).$

Decision Variables:

$x_p: Binary\ variable = \begin{cases} 1 & Plant\ is\ built\ at\ location\ p \\ 0 & Otherwise \end{cases}$

$y_{sp}: The\ amount\ of\ biomass\ transported\ from\ county\ s\ to\ biorefinery\ p\ (tonne).$

$trips_{sp}: Integer\ variable. Number\ of\ truck\ trips\ needed\ to\ transport\ biomass\ from\ supplier\ s\ to\ plant\ p.$

Objective Function:

$Investment\ cost + transportation\ cost + loading\ cost.$

$$Minimize\ \zeta = \sum_{p \in PSet} InvCost_p * x_p + \sum_{s \in SSet, p \in PSet} (TransCost_{sp} * Dist_{sp} * y_{sp}) + \sum_{s \in SSet, p \in PSet} LoadCost * trips_{sp}$$

Constraints:

Supply constraints: A supplier can only supply the amount of biomass that it has available.

$$\sum_{p \in PSet} y_{sp} \le Supply_s, \qquad \forall s \in SSet$$

Plant constraints: A plant can only process biomass up to its capacity, and only after it is built.

$$\sum_{s \in SSet} Yield * y_{sp} \leq PlantCap * x_p, \qquad \forall p \in PSet$$

Bioethanol production requirement: Ensure that the total bioethanol produced meets the demand.

$$\sum_{s \in SSet, p \in PSet} Yield * y_{sp} \geq Demand$$

Truck trips constraints: Ensures the number of truck trips needed.

$$y_{sp} \leq TruckCap * trips_{sp}, \qquad \forall s \in SSet, p \in PSet$$

Binary constraints: Ensures that x_p is binary.

$$x_p \in \{0,1\}, \qquad \forall p \in PSet$$

Integer constraints: Ensures that $trips_{sp}$ is a non-negative integer. $\mathbb{Z}_{\geq} = \{0,1,2, \dots\}$.

$$trips_{sp} \in \mathbb{Z}_{\geq}$$

Non-negativity constraint: Ensures that all biomass transported, and number of trips is non-negative.

$$y_{sp} \geq 0, \qquad \forall s \in SSet, h \in HSet$$

$$trips_{sp} \geq 0, \qquad \forall s \in SSet, h \geq HSet$$

Result

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Optimal Solution:
-----------------------------------------------
Total cost: $8 501 421 861
Total bioethanol produced: 500 000 000 liters
Total biomass used: 2 155 172 tonne
Total number of open plants: 11

Open Facilities:
Type            | Location
-----------------------------
Plant           | 541
Plant           | 9063
Plant           | 9071
Plant           | 9102
Plant           | 9107
Plant           | 9155
Plant           | 9178
Plant           | 9183
Plant           | 9203
Plant           | 10058
Plant           | 10066
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Flow of Biomass from Suppliers to Plants (Part 1):

Supplier	Plant	Flow (tonne)
48001	9063	13 131.97
48007	10066	308.18
48009	9203	19 802.14
48015	9178	17 336.34
48021	541	13 091.86
48023	10058	8 499.47
48025	10066	19 158.32
48027	541	23 892.32
48029	541	9 920.54
48031	541	12 994.53
48035	9102	22 418.59
48039	9155	40 515.13
48041	9063	14 630.92
48049	9203	16 532.73
48051	9063	16 489.00
48053	541	18 196.87
48055	541	10 856.18
48057	10066	15 211.35
48059	9102	18 068.53
48063	9183	2 444.57
48071	9178	13 382.16
48073	9063	10 109.57
48077	9102	25 528.76
48083	9102	24 381.26
48085	9183	19 739.69
48089	9178	24 916.71
48091	541	7 004.34
48093	9203	14 186.85
48097	9183	23 662.35
48099	9107	22 389.68
48113	9071	4 701.77
48119	9183	8 402.84
48121	9183	19 303.58
48123	10066	20 410.85
48133	9203	12 072.45
48139	9071	28 926.45
48143	9203	17 013.47
48145	9063	33 452.80
48147	9183	28 447.25
48149	9178	21 806.70
48155	10058	14 605.36
48157	9178	25 380.59
48159	9183	4 382.27
48161	9071	18 570.48
48167	9155	5 468.82
48175	10066	18 902.89
48177	10066	20 945.06
48181	9183	23 869.32
48183	9071	1 255.06
48185	9178	18 602.03
48187	541	14 521.50
48193	9102	17 843.20
48197	10058	13 061.60
48201	9178	12 916.53
48209	541	8 833.26
48213	9071	13 595.33
48217	9107	34 471.54
48221	9203	6 619.83
48223	9183	17 434.18
48225	9063	17 712.96
48231	9071	21 721.83
48237	9203	19 014.92
48239	10066	34 219.81

Flow of Biomass from Suppliers to Plants (Part 2):

Supplier	Plant	Flow (tonne)
48245	9178	21 409.90
48249	10066	13 373.97
48251	9102	19 463.88
48255	10066	15 171.99
48257	9071	22 038.75
48259	541	12 872.84
48273	10066	22 665.90
48277	9183	25 697.27
48281	541	16 681.00
48285	10066	25 734.28
48287	9063	12 660.40
48289	9063	21 352.90
48291	9178	14 693.94
48293	9063	26 796.15
48297	10066	14 654.24
48299	541	16 968.95
48307	9102	20 408.12
48309	9107	31 254.14
48313	9063	14 092.38
48319	541	15 500.00
48321	9155	38 552.25
48331	9063	26 627.08
48333	541	16 684.33
48337	9183	18 557.11
48339	9178	5 612.19
48343	9183	3 542.48
48349	9071	30 659.84
48355	10066	30 669.33
48361	9178	2 692.72
48363	9203	20 991.00
48367	9203	16 140.04
48373	9178	4 674.47
48379	9071	4 338.88
48387	9183	20 920.46
48391	10066	25 089.06
48395	9063	19 015.77
48397	9071	3 112.52
48399	9102	10 861.21
48407	9178	3 798.86
48409	10066	24 653.38
48411	541	20 076.02
48417	9203	16 592.12
48423	9071	8 037.38
48425	9107	2 976.96
48429	9203	17 321.41
48439	9203	5 453.29
48447	9203	18 246.35
48449	9183	6 119.62
48453	541	11 662.93
48459	9071	6 682.33
48467	9071	13 771.58
48469	10066	27 555.55
48471	9178	11 203.68
48473	9178	13 990.84
48477	9178	17 817.90
48481	9178	45 431.14
48485	9102	11 898.75
48487	10058	24 852.43
48491	541	30 142.91
48493	10066	12 042.40
48497	9203	18 499.44
48499	9071	6 658.24
48503	9203	20 167.74

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Task 2

Model

Sets:

$SSet$: $Set\ of\ suppliers\ (counties)$.

$PSet$: $Set\ of\ potential\ plants\ (biorefineries)$.

$HSet$: $Set\ of\ potential\ hubs$.

Parameters:

$Supply_s$: $Supply\ of\ biomass\ \ from\ supplier\ s\ (tonne)$.

$Yield = 232$: $Conversion\ yield\ of\ bioethanol\ (liters\ per\ tonne\ of\ biomass)$.

$PlantCap = 152\ 063\ 705$: $Annual\ conversion\ capacity\ for\ each\ plant\ (liters)$.

$HubCap = 300\ 000$: $Annual\ biomass\ processing\ capacity\ for\ each\ hub\ (tonne)$.

$Demand = 500\ 000\ 000$: $Total\ bioethanol\ demand\ (production\ target)\ (liters)$.

$InvCost_p$: $Investment\ cost\ to\ maintain\ a\ plant\ at\ location\ p\ (\$)$.

$HubInvCost_h$: $Investment\ cost\ to\ maintain\ a\ hub\ at\ location\ h\ (\$)$.

$TransCostSH_{sh}$: $Transportation\ cost\ from\ supplier\ s\ to\ hub\ h\ \left(\frac{\$}{tonne}\ per\ km\right)$.

$TransCostHP_{hp}$: $Transportation\ cost\ from\ hub\ h\ to\ plant\ p\ \left(\frac{\$}{tonne}\ per\ km\right)$.

$DistSH_{sh}$: $Distance\ from\ supplier\ s\ to\ hub\ h\ (km)$.

$DistSP_{sp}$: $Distance\ from\ hub\ h\ to\ plant\ p\ (km)$.

$LoadCostTruck = 10\ 000$: $Combined\ loading\ and\ unloading\ cost\ for\ each\ truck\ trip\ (\$)$.

$LoadCostTrain = 60\ 000$: $Combined\ loading\ and\ unloading\ cost\ for\ each\ train\ trip\ (\$)$.

$TruckCap = 500$: $Capacity\ of\ truck\ (tonne)$.

$TrainCap = 20\ 000$: $Capacity\ of\ train\ (tonne)$.

Decision Variables:

x_p: $Binary\ variable = \begin{cases} 1 & Plant\ is\ built\ at\ location\ p \\ 0 & Otherwize \end{cases}$

z_h: $Binary\ variable = \begin{cases} 1 & Hub\ is\ built\ at\ location\ h \\ 0 & Otherwize \end{cases}$

ySH_{sh}: $The\ amount\ of\ biomass\ transported\ from\ supplier\ s\ to\ hub\ h\ (tonne)$.

yHP_{hp}: $The\ amount\ of\ biomass\ transported\ from\ hub\ h\ to\ plant\ p\ (tonne)$.

$tripsSH_{sh}$: $Integer\ variable. Number\ of\ truck\ trips\ needed\ to\ transport\ biomass\ from\ supplier\ s\ to\ hub\ h$.

$tripsHP_{hp}$: $Integer\ variable. Number\ of\ train\ trips\ needed\ to\ transport\ biomass\ from\ hub\ h\ to\ plant\ p$.

Objective Function:

$Plant\ investment\ cost + hub\ investment\ cost + transport\ cost\ from\ s\ to\ h + loading\ cost\ from\ s\ to\ h + transport\ cost\ from\ h\ to\ p + loading\ cost\ from\ h\ to\ p.$

$$
\begin{aligned}
Minimize\ \zeta = & \sum_{p \in PSet} InvCost_p * x_p + \sum_{h \in HSet} HubInvCost * z_h \\
& + \sum_{s \in SSet, h \in HSet} (TransCostSH_{sh} * DistSH_{sh} * ySH_{sh}) \\
& + \sum_{s \in SSet, h \in HSet} (LoadCostTruck * tripsSH_{sh}) \\
& + \sum_{h \in HSet, p \in PSet} \left(TransCostHP_{hp} * DistHP_{hp} * yHP_{hp}\right) \\
& + \sum_{h \in HSet, p \in PSet} \left(LoadCostTrain * tripsHP_{hp}\right)
\end{aligned}
$$

Constraints:

Supply constraints: A supplier can only supply the amount of biomass that it has available.

$$\sum_{h \in HSet} ySH_{sh} \leq Supply_s, \qquad \forall s \in SSet$$

Hub constraints: A hub can only receive and send biomass after it is built.

$$\sum_{s \in SSet} ySH_{sh} \leq HubCap * z_h, \qquad \forall h \in HSet$$

$$\sum_{p \in PSset} yHP_{hp} \leq HubCap * z_h, \qquad \forall h \in HSet$$

Hub balance constraints: Quantity biomass received equals quantity biomass sent.

$$\sum_{s \in SSet} ySH_{sh} = \sum_{p \in PSet} yHP_{hp}, \qquad \forall h \in HSet$$

Plant constraints: A plant can only process biomass up to its capacity, and only after it is built.

$$\sum_{h \in HSet} Yield * yHP_{hp} \leq PlantCap * x_p, \qquad \forall p \in PSet$$

Bioethanol production requirement: Ensure that the total bioethanol produced meets the demand.

$$\sum_{h \in HSet, p \in PSet} Yield * yHP_{hp} \geq Demand$$

Truck trips constraints: Ensures the number of truck trips needed.

$$ySH_{sh} \leq TruckCap * tripsSH_{sh}, \qquad \forall s \in SSet, h \in HSet$$

Train trips constraints: Ensures the number of train trips needed.

$$yHP_{hp} \leq TrainCap * tripsHP_{hp}, \quad \forall h \in HSet, p \in PSet$$

Binary constraints: Ensures that x_p and z_h is binary.

$$x_p \in \{0,1\}, \quad \forall p \in PSet$$

$$z_h \in \{0,1\}, \quad \forall h \in HSet$$

Integer constraints: Ensures that $tripSH_{sh}$ and $tripsHP_{hp}$ is a non-negative integer. $\mathbb{Z}_{\geq} = \{0,1,2,\ldots\}$.

$$tripsSH_{sh} \in \mathbb{Z}_{\geq}, \quad \forall s \in SSet, h \geq HSet$$

$$tripsHP_{HP} \in \mathbb{Z}_{\geq}, \quad \forall s \in SSet, h \geq HSet$$

Non-negativity constraint: Ensures that all biomass transported, and number of trips is non-negative.

$$ySH_{sh} \geq 0, \quad \forall s \in SSet, h \in HSet$$

$$yHP_{hp} \geq 0, \quad \forall h \in HSet, p \in PSet$$

$$tripsSH_{sh} \geq 0, \quad \forall s \in SSet, h \geq HSet$$

$$tripsHP_{hp} \geq 0, \quad \forall h \in HSet, p \in PSet$$

Result

Optimal Solution:

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---------------------------------------------
Total cost: $5 135 420 807
Total bioethanol produced: 500 000 000 liters
Total biomass used: 2 155 172 tonne
Total number of open plants: 8
Total number of open hubs: 31
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Flow of Biomass from Hubs to Plants:

Hub	Plant	Flow (tonne)
17201	9183	108 245.57
17218	9183	45 271.35
17359	9178	45 431.14
17372	541	125 485.89
17395	9060	107 241.07
17404	10066	31 058.15
17447	9178	45 983.95
17466	9203	103 000.38
17507	541	97 756.08
17592	9047	126 223.64
17620	9091	47 513.87
17679	10066	130 240.08
17717	9060	33 452.80
17784	9091	57 229.65
17792	9183	50 169.08
17822	9060	23 892.32
17829	9178	146 831.35
17896	9047	62 702.62
17931	9091	59 860.69
17934	9203	167 480.44
17942	10066	37 981.14
17943	10066	44 555.57
18029	9178	38 552.25
18042	9178	62 062.48
18063	9047	31 254.14
18082	10066	34 219.81
18127	10066	75 347.49
18286	9047	26 796.15
18288	9060	87 603.47
18294	9047	62 659.12
18303	9060	39 070.68

Open Facilities:

Type	Location
Plant	541
Plant	9047
Plant	9060
Plant	9091
Plant	9178
Plant	9183
Plant	9203
Plant	10066
Hub	17201
Hub	17218
Hub	17359
Hub	17372
Hub	17395
Hub	17404
Hub	17447
Hub	17466
Hub	17507
Hub	17592
Hub	17620
Hub	17679
Hub	17717
Hub	17784
Hub	17792
Hub	17822
Hub	17829
Hub	17896
Hub	17931
Hub	17934
Hub	17942
Hub	17943
Hub	18029
Hub	18042
Hub	18063
Hub	18082
Hub	18127
Hub	18286
Hub	18288
Hub	18294
Hub	18303

Flow of Biomass from Suppliers to Hubs (Part 1):

Supplier	Hub	Flow (tonne)
48001	18288	13 131.97
48007	17943	308.18
48009	17784	19 802.14
48015	17829	17 336.34
48021	17507	13 091.86
48023	17620	22 661.44
48025	17943	19 158.32
48027	17822	23 892.32
48031	17372	12 994.53
48035	17896	22 418.59
48037	17201	12 619.55
48039	17447	40 515.13
48041	17395	14 630.92
48047	17942	127.20
48051	17395	16 489.00
48053	17507	18 196.87
48055	17507	10 856.18
48057	17679	15 211.35
48059	17466	18 068.53
48063	17201	2 444.57
48071	17829	13 382.16
48073	18288	10 109.57
48077	17784	25 528.76
48085	17218	19 739.69
48089	17829	24 916.71
48091	17507	4 972.08
48093	17934	14 186.85
48097	17218	1 662.35
48097	17931	22 000.00
48099	18303	22 389.68
48113	18294	4 701.77
48119	17201	8 402.84
48121	17931	19 303.58
48123	17679	20 410.85
48131	17404	388.82
48133	17934	12 072.45
48139	17592	28 926.45
48143	17934	17 013.47
48145	17717	33 452.80
48147	17792	28 447.25
48149	18042	21 806.70
48151	17466	8 034.70
48157	17829	25 380.59
48159	17201	4 382.27
48161	17592	18 570.48
48167	17447	5 468.82
48171	17372	22 845.15
48175	17679	18 902.89
48177	17679	20 945.06
48181	17218	23 869.32
48185	17829	18 602.03
48187	18042	14 521.50
48193	17896	17 843.20
48201	17829	12 916.53
48207	17466	21 575.34
48209	17507	8 833.26
48213	17592	13 595.33
48217	17592	34 471.54
48221	17934	6 619.83
48223	17201	17 434.18
48225	18288	17 712.96

Flow of Biomass from Suppliers to Hubs (Part 2):

Supplier	Hub	Flow (tonne)
48231	17792	21 721.83
48237	17934	19 014.92
48239	18082	34 219.81
48249	18127	13 373.97
48251	17896	19 463.88
48253	17466	19 911.01
48255	17679	15 171.99
48257	18294	22 038.75
48261	17942	37 853.94
48273	18127	22 665.90
48277	17201	25 697.27
48281	18303	16 681.00
48285	18042	25 734.28
48287	17395	12 660.40
48289	18288	21 352.90
48291	17829	14 693.94
48293	18286	26 796.15
48297	18127	14 654.24
48299	17372	16 968.95
48307	17372	20 408.12
48309	18063	31 254.14
48313	18288	14 092.38
48319	17372	15 508.80
48321	18029	38 552.25
48331	17395	26 627.08
48333	17372	16 684.33
48337	17931	18 557.11
48339	17829	5 612.19
48343	17201	3 542.48
48349	17592	30 659.84
48355	17404	30 669.33
48363	17934	20 991.00
48367	17934	16 140.04
48379	18294	4 338.88
48387	17201	20 920.46
48391	17943	25 089.06
48395	17395	19 015.77
48397	18294	3 112.52
48409	18127	24 653.38
48411	17372	20 076.02
48417	17466	16 592.12
48423	18294	8 037.38
48425	17896	2 976.96
48429	17934	17 321.41
48439	17934	5 453.29
48441	17466	18 818.67
48449	17201	6 119.62
48453	17507	11 662.93
48459	17201	6 682.33
48467	18294	13 771.58
48469	17679	27 555.55
48471	18288	11 203.68
48473	17829	13 990.84
48477	17395	17 817.90
48481	17359	45 431.14
48485	17784	11 898.75
48487	17620	24 852.43
48491	17507	30 142.91
48493	17679	12 042.40
48497	17934	18 499.44
48499	18294	6 658.24
48503	17934	20 167.74

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Task 3

Model

Sets:

$SSet$: $Set\ of\ suppliers\ (counties)$.

$PSet$: $Set\ of\ potential\ plants\ (biorefineries)$.

$HSet$: $Set\ of\ potential\ hubs$.

$TPSet$: $Set\ of\ the\ single\ third\ party\ supplier$.

Parameters:

$Supply_s$: $Supply\ of\ biomass\ \ from\ supplier\ s\ (tonne)$.

$Yield = 232$: $Conversion\ yield\ of\ bioethanol\ (liters\ per\ tonne\ of\ biomass)$.

$PlantCap = 152\ 063\ 705$: $Annual\ conversion\ capacity\ for\ each\ plant\ (liters)$.

$HubCap = 300\ 000$: $Annual\ biomass\ processing\ capacity\ for\ each\ hub\ (tonne)$.

$Demand = 500\ 000\ 000$: $Total\ bioethanol\ demand\ (production\ target)\ (liters)$.

$InvCost_p$: $Investment\ cost\ to\ maintain\ a\ plant\ at\ location\ p\ (\$)$.

$HubInvCost_h$: $Investment\ cost\ to\ maintain\ a\ hub\ at\ location\ h\ (\$)$.

$TransCostSH_{sh}$: $Transportation\ cost\ from\ supplier\ s\ to\ hub\ h\ \left(\frac{\$}{tonne}\ per\ km\right)$.

$TransCostHP_{hp}$: $Transportation\ cost\ from\ hub\ h\ to\ plant\ p\ \left(\frac{\$}{tonne}\ per\ km\right)$.

$DistSH_{sh}$: $Distance\ from\ supplier\ s\ to\ hub\ h\ (km)$.

$DistSP_{sp}$: $Distance\ from\ hub\ h\ to\ plant\ p\ (km)$.

$LoadCostTruck = 10\ 000$: $Combined\ loading\ and\ unloading\ cost\ for\ each\ truck\ trip\ (\$)$.

$LoadCostTrain = 60\ 000$: $Combined\ loading\ and\ unloading\ cost\ for\ each\ train\ trip\ (\$)$.

$TruckCap = 500$: $Capacity\ of\ truck\ (tonne)$.

$TrainCap = 20\ 000$: $Capacity\ of\ train\ (tonne)$.

$ThirdPartyCost = 2000$: $Cost\ of\ 1\ tonne\ biomass\ from\ the\ third\ party\ supplier\ (\$)$.

Decision Variables:

x_p: $Binary\ variable = \begin{cases} 1 & Plant\ is\ built\ at\ location\ p \\ 0 & Otherwize \end{cases}$

z_h: $Binary\ variable = \begin{cases} 1 & Hub\ is\ built\ at\ location\ h \\ 0 & Otherwize \end{cases}$

ySH_{sh}: $The\ amount\ of\ biomass\ transported\ from\ supplier\ s\ to\ hub\ h\ (tonne)$.

yHP_{hp}: $The\ amount\ of\ biomass\ transported\ from\ hub\ h\ to\ plant\ p\ (tonne)$.

$yTP_h: The\ amount\ of\ biomass\ transported\ from\ the\ third\ party\ supplier\ to\ hub\ h\ (tonne).$

$tripsSH_{sh}: Integer\ variable. Number\ of\ truck\ trips\ needed\ to\ transport\ biomass\ from\ supplier\ s\ to\ hub\ h.$

$tripsHP_{hp}: Integer\ variable. Number\ of\ train\ trips\ needed\ to\ transport\ biomass\ from\ hub\ h\ to\ plant\ p.$

Objective Function:

$Plant\ investment\ cost + hub\ investment\ cost + transport\ cost\ from\ s\ to\ h + loading\ cost\ from\ s\ to\ h + transport\ cost\ from\ h\ to\ p + loading\ cost\ from\ h\ to\ p + third\ party\ cost.$

$$\begin{aligned} Minimize\ \zeta = & \sum_{p \in PSet} InvCost_p * x_p + \sum_{h \in HSet} HubInvCost * z_h \\ & + \sum_{s \in SSet, h \in HSet} (TransCostSH_{sh} * DistSH_{sh} * ySH_{sh}) \\ & + \sum_{s \in SSet, h \in HSet} (LoadCostTruck * tripsSH_{sh}) \\ & + \sum_{h \in HSet, p \in PSet} \left(TransCostHP_{hp} * DistHP_{hp} * yHP_{hp}\right) \\ & + \sum_{h \in HSet, p \in PSet} \left(LoadCostTrain * tripsHP_{hp}\right) + \sum_{h \in H} ThirdPartyCost * yTP_h \end{aligned}$$

Constraints:

Supply constraints: A supplier can only supply the amount of biomass it has available.

$$\sum_{h \in HSet} ySH_{sh} \leq Supply_s, \qquad \forall s \in SSet$$

Hub constraints: A hub can only receive and send biomass after it is built.

$$\sum_{s \in SSet} (ySH_{sh}) + yTP_h \leq HubCap * z_h, \qquad \forall h \in HSet$$

$$\sum_{p \in PSset} yHP_{hp} \leq HubCap * z_h, \qquad \forall h \in HSet$$

Hub balance constraints: Quantity biomass received equals quantity biomass sent.

$$\sum_{s \in SSet} (ySH_{sh}) + yTP_h = \sum_{p \in PSet} yHP_{hp}, \qquad \forall h \in HSet$$

Plant constraints: A plant can only process biomass up to its capacity, and only after it is built.

$$\sum_{h \in HSet} Yield * yHP_{hp} \leq PlantCap * x_p, \qquad \forall p \in PSet$$

Bioethanol production requirement: Ensure that the total bioethanol produced meets the demand.

$$\sum_{h \in HSet, p \in PSet} Yield * yHP_{hp} \geq Demand$$

Truck trips constraints: Ensures the number of truck trips needed.

$$ySH_{sh} \leq TruckCap * tripsSH_{sh}, \qquad \forall s \in SSet, h \in HSet$$

Train trips constraints: Ensures the number of train trips needed.

$$yHP_{hp} \leq TrainCap * tripsHP_{hp}, \qquad \forall h \in HSet, p \in PSet$$

Binary constraints: Ensures that x_p and z_h is binary.

$$x_p \in \{0,1\}, \qquad \forall p \in PSet$$

$$z_h \in \{0,1\}, \qquad \forall h \in HSet$$

Integer constraints: Ensures that $tripSH_{sh}$ and $tripsHP_{hp}$ is a non-negative integer. $\mathbb{Z}_{\geq} = \{0,1,2, \ldots\}$.

$$tripsSH_{sh} \in \mathbb{Z}_{\geq}, \qquad \forall s \in SSet, h \geq HSet$$

$$tripsHP_{HP} \in \mathbb{Z}_{\geq}, \qquad \forall s \in SSet, h \geq HSet$$

Non-negativity constraint: Ensures that all biomass transported, and number of trips is non-negative.

$$ySH_{sh} \geq 0, \qquad \forall s \in SSet, h \in HSet$$

$$yHP_{hp} \geq 0, \qquad \forall h \in HSet, p \in PSet$$

$$yTP_h \geq 0, \qquad \forall h \in HSet$$

$$tripsSH_{sh} \geq 0, \qquad \forall s \in SSet, h \geq HSet$$

$$tripsHP_{hp} \geq 0, \qquad \forall h \in HSet, p \in PSet$$

Result

```
Optimal Solution:
-----------------------------------------------------------------
Total Cost: $7 144 532 489
Total bioethanol produced: 800 000 000 liters
Total biomass used (including third party): 3 448 276 tonne
Total biomass sourced from third party supplier: 2 052 787 tonne
Total biomass used (excluding third party): 1 395 489 tonne
Total number of open plants: 7
Total number of open hubs: 23
```

Flow of Biomass from Third Party Supplier to Hubs:

Third Party	Hub	Flow (tonne)
ThirdParty	17218	213 425.07
ThirdParty	17359	229 652.15
ThirdParty	17395	210 707.75
ThirdParty	17447	254 016.05
ThirdParty	17592	173 776.36
ThirdParty	17679	217 919.36
ThirdParty	17792	229 823.18
ThirdParty	17829	230 375.70
ThirdParty	17934	192 008.34
ThirdParty	17943	101 083.22

Open Facilities:

Type	Location
Plant	9044
Plant	9047
Plant	9060
Plant	9178
Plant	9183
Plant	9203
Plant	10066
Hub	17201
Hub	17218
Hub	17359
Hub	17395
Hub	17404
Hub	17447
Hub	17507
Hub	17592
Hub	17679
Hub	17717
Hub	17792
Hub	17822
Hub	17829
Hub	17896
Hub	17934
Hub	17943
Hub	18029
Hub	18042
Hub	18063
Hub	18082
Hub	18286
Hub	18288
Hub	18294

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Flow of Biomass from Suppliers to Hubs (Part 1):

Supplier	Hub	Flow (tonne)
48001	18288	13 131.97
48007	17943	308.18
48015	17829	17 336.34
48021	18042	7 906.02
48025	17943	19 158.32
48027	17822	23 892.32
48035	17896	22 418.59
48039	17447	40 515.13
48041	17395	14 500.00
48051	17395	16 489.00
48053	17507	18 194.16
48057	17679	15 211.35
48085	17218	19 739.69
48089	17359	24 916.71
48097	17218	23 662.35
48099	17822	22 389.68
48113	18294	4 701.77
48119	17201	8 402.84
48121	17218	19 303.58
48123	17679	20 410.85
48133	17934	12 072.45
48139	17592	28 926.45
48143	17934	17 013.47
48145	17717	33 452.80
48147	17792	28 447.25
48149	18042	21 806.70
48157	17829	25 380.59
48159	17201	3 000.00
48161	17592	18 570.48
48167	17447	5 468.82
48175	17679	18 902.89
48181	17218	23 869.32
48193	17896	17 843.20
48201	17829	12 916.53
48213	17592	13 595.33

Flow of Biomass from Suppliers to Hubs (Part 2):

Supplier	Hub	Flow (tonne)
48217	17592	34 471.54
48221	17896	6 619.83
48223	17201	17 434.18
48231	17792	21 721.83
48237	17934	19 000.00
48239	18082	34 219.81
48251	17896	19 463.88
48257	18294	22 038.75
48277	17201	25 697.27
48285	18042	25 734.28
48287	17395	12 660.40
48289	18288	21 352.90
48293	18286	26 796.15
48309	18063	31 254.14
48313	18288	14 092.38
48321	18029	38 552.25
48331	17395	26 627.08
48349	17592	30 659.84
48355	17404	30 669.33
48363	17934	20 991.00
48367	17934	16 140.04
48379	18294	4 338.88
48387	17201	20 920.46
48391	17943	25 089.06
48395	17395	19 015.77
48397	18294	3 112.52
48409	17943	24 653.38
48425	17896	2 976.96
48429	17934	17 321.41
48439	17934	5 453.29
48453	17507	11 662.93
48467	18294	13 771.58
48469	17679	27 555.55
48473	17829	13 990.84
48481	17359	45 431.14
48491	17507	30 142.91

Flow of Biomass from Hubs to Plants:

Hub	Plant	Flow (tonne)
17201	9183	75 454.75
17218	9183	300 000.00
17359	9178	300 000.00
17395	9060	300 000.00
17404	10066	30 669.33
17447	9044	300 000.00
17507	9060	60 000.00
17592	9047	300 000.00
17679	10066	300 000.00
17717	9060	33 452.80
17792	9183	279 992.26
17822	9060	46 282.01
17829	9178	300 000.00
17896	9047	69 322.45
17934	9203	300 000.00
17943	10066	170 292.16
18029	9044	38 552.25
18042	9178	55 447.00
18063	9047	31 254.14
18082	10066	34 219.81
18286	9047	26 796.15
18288	9060	48 577.26
18294	9047	47 963.50