

**IMPLEMENTATION OF BUSINESS OPTIMIZATION MODELS**

**PROJECT ASSIGNMENT**

**BY**

|  |  |
| --- | --- |
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**PRESENTED TO**

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# Problem 1: Project management at BPDC

Indices:

𝑖 ∈ 𝐼 = {𝐴, 𝐵, 𝐶, … , 𝑄, 𝐸𝑁𝐷} ∶ 𝑇ℎ𝑒 𝑑𝑖𝑓𝑓𝑒𝑟𝑒𝑛𝑡 𝑎𝑐𝑡𝑖𝑣𝑖𝑡𝑖𝑒𝑠

Parameters:

𝑡>: 𝐷𝑢𝑟𝑎𝑡𝑖𝑜𝑛 𝑜𝑓 𝑎𝑐𝑡𝑖𝑣𝑖𝑡𝑦 𝑖 (𝑖𝑛 𝑤𝑒𝑒𝑘𝑠)

Decision variables:

𝑋>: 𝐸𝑎𝑟𝑙𝑖𝑒𝑠𝑡 𝑠𝑡𝑎𝑟𝑡 𝑡𝑖𝑚𝑒 𝑜𝑓 𝑎𝑐𝑡𝑖𝑣𝑖𝑡𝑦 𝑖

Objective function:

𝑀𝑖𝑛 K 𝑋>

>∈𝐼

Constraints:

𝑋𝐶 ≥ 𝑋𝐴 + 𝑡𝐴 (Construction camps and infrastructure (Activity C) cannot begin before roads are finished (Activity A))

𝑋𝐷 ≤ 𝑋𝑃 (Relocation of residents (Activity D) must be finished before 2nd cofferdam is removed (Activity P))

𝑋𝐸 ≥ 𝑋𝐴 + 𝑡𝐴 (Concrete plant (Activity E) cannot begin before roads are finished (Activity A))

𝑋𝐸 ≤ 𝑋𝐽 (Concrete plant (Activity E) must be finished before concrete works (Activity J))

𝑋𝐹 ≥ 𝑋𝐴 + 𝑡𝐴 (Build 1st concrete plant (Activity F) when site is ready (Activity A, B and C))

𝑋𝐹 ≥ 𝑋𝐵 + 𝑡𝐵 (Build 1st concrete plant (Activity F) when site is ready (Activity A, B and C))

𝑋𝐹 ≥ 𝑋𝐶 + 𝑡𝐶 (Build 1st concrete plant (Activity F) when site is ready (Activity A, B and C))

𝑋𝐺 ≥ 𝑋𝐹 + 𝑡𝐹 (Excavation of diversion channel (Activity G) after 1st cofferdam is finished (Activity F))

𝑋𝐻 ≥ 𝑋𝐺 + 𝑡𝐺 (Remove 1st cofferdam (Activity H) after excavation is finished (Activity G))

𝑋𝐼 ≥ 𝑋𝐵 + 𝑡𝐵 (Excavation (Activity I) can start when site is ready (Activity A, B and C))

𝑋𝐼 ≥ 𝑋𝐶 + 𝑡𝐶 (Excavation (Activity I) can start when site is ready (Activity A, B and C))

𝑋𝐽 ≥ 𝑋𝐼 + 0.5𝑡𝐼 (Concrete (Activity J) cannot start before half of excavation is realized (Activity I))

𝑋𝐾 ≥ 𝑋𝐽 + 0.5𝑡𝐽 (Metal work (Activity K) cannot start before half of concrete is realized (Activity J))

𝑋𝐿 ≥ 𝑋𝐻 + 𝑡𝐻 (2nd cofferdam (Activity L) can start after 1st cofferdam is removed (Activity H))

𝑋𝑀 ≥ 𝑋𝐿 + 𝑡𝐿 (Divert water to diversion channel (Activity M) after 2nd cofferdam is finished (Activity L))

𝑋𝑁 ≥ 𝑋𝐴 + 𝑡𝐴 (Excavation (Activity N) can start when site is ready (Activity A, B and C))

𝑋𝑁 ≥ 𝑋𝐵 + 𝑡𝐵 (Excavation (Activity N) can start when site is ready (Activity A, B and C))

𝑋𝑁 ≥ 𝑋𝐶 + 𝑡𝐶 (Excavation (Activity N) can start when site is ready (Activity A, B and C))

𝑋a ≥ 𝑋𝑀 + 𝑡𝑀 (Concrete and metal work (Activity O) can start after construction site is dry (Activity M))

𝑋a ≥ 𝑋𝑁 + 0.5𝑡𝑁 (Concrete and metal work (Activity O) can start after half of excavation is realized (Activity N))

𝑋𝑃 ≥ 𝑋a + 𝑡a (Remove 2nd cofferdam (Activity P) after concrete & metal work (Activity O))

2

𝑋b ≥ 𝑋a + 3 𝑡a

(Installation of units (Activity Q) after 2/3 of concrete & metal is finished (Activity O))

𝑋𝐸𝑁𝐷 ≥ 𝑋𝑃 + 𝑡𝑃 (End must be after all activities that are not predecessors (Activities P, Q, K, N, I and J))

𝑋𝐸𝑁𝐷 ≥ 𝑋b + 𝑡b (End must be after all activities that are not predecessors (Activities P, Q, K, N, I and J))

𝑋𝐸𝑁𝐷 ≥ 𝑋𝐾 + 𝑡𝐾 (End must be after all activities that are not predecessors (Activities P, Q, K, N, I and J))

𝑋𝐸𝑁𝐷 ≥ 𝑋𝑁 + 𝑡𝑁 (End must be after all activities that are not predecessors (Activities P, Q, K, N, I and J))

𝑋𝐸𝑁𝐷 ≥ 𝑋𝐼 + 𝑡𝐼 (End must be after all activities that are not predecessors (Activities P, Q, K, N, I and J))

𝑋𝐸𝑁𝐷 ≥ 𝑋𝐽 + 𝑡𝐽 (End must be after all activities that are not predecessors (Activities P, Q, K, N, I and J))

1. The proposed earliest start time of the activities are the following:

|  |  |  |
| --- | --- | --- |
| **Activity** | **Activity Code** | **Start time (TI)** |
| Access roads | A | 0 |
| Railway | B | 0 |
| Construction camps and infrastructure | C | 90 |
| Relocation of residents | D | 0 |
| Concrete plant | E | 90 |
| Build 1st cofferdam | F | 150 |
| Excavation of diversion channel | G | 168 |
| Remove 1st cofferdam | H | 240 |
| Excavation | I | 150 |
| Concrete | J | 220 |
| Metal work | K | 260 |
| 2nd cofferdam | L | 252 |
| Divert water to diversion channel | M | 282 |
| Excavation | N | 150 |
| Concrete and metal work | O | 294 |
| Remove 2nd cofferdam | P | 414 |
| Installation of units | Q | 374 |
| **End of activities** | **END** | **464** |

1. According to the calendar, electricity production will start 464 weeks after the site preparation begins. Therefore, if site preparation starts in March 2020 then electricity production will start in January 2029.

**3)**

Q P O N M L K J

I H G F E D C B A

EST

Duration SLACK

0 100 200 300 400 500

As it can be seen in the graph above, it is not possible to accelerate the project’s duration. There is a critical path, meaning that within that path there is no slack time to use to accelerate the project. The critical path is : A, C, F, G, H, L, M, O, Q.

# Problem 2: Oswal, Brett & Associates

Indices:

𝑖 ∈ 𝑁 = {𝑈, 𝐴, 𝐺, 𝐸, 𝐼, 𝐽, 𝑆, 𝐶} : The different nodes (currencies)

(𝑖, 𝑗) ∈ 𝐴 : The different directed arcs

Parameters:

𝑡>j: 𝑡𝑟𝑎𝑛𝑠𝑎𝑐𝑡𝑖𝑜𝑛 𝑓𝑒𝑒 𝑓𝑜𝑟 𝑎𝑟𝑐 (𝑖, 𝑗) (𝑖𝑛 %)

𝑒>j: 𝑒𝑥𝑐ℎ𝑎𝑛𝑔𝑒 𝑟𝑎𝑡𝑒 𝑓𝑜𝑟 𝑎𝑟𝑐 (𝑖, 𝑗)

𝑓>: 𝑒𝑥𝑡𝑒𝑟𝑛𝑎𝑙 𝑓𝑙𝑜𝑤 𝑎𝑡 𝑛𝑜𝑑𝑒 𝑖

Decision variables:

𝑋>j: 𝑓𝑙𝑜𝑤 𝑜𝑓 𝑐𝑢𝑟𝑟𝑒𝑛𝑐𝑦 𝑜𝑛 𝑎𝑟𝑐 (𝑖, 𝑗) (millions)

**1)**

If we convert each non-U.S. currency OB&A owns directly into U.S. dollars, we get the following equation:

K 𝑋>𝑈𝑒>𝑈(1 − 𝑡>𝑈) ∀𝑖 ∈ {𝐸, 𝐽, 𝐶}

>:(>,𝑈)∈𝐴

, where in this case 𝑋>𝑈 is equal to the external flow of EUR, JPY and CHF currencies, where

𝑓𝐸 = 6, 𝑓𝐽 = 1,665.31 and 𝑓𝐶 = 30.

This results in **52.73 million USD**.

**2)**

Objective function:

Constraints :

𝑀𝑎𝑥 − 𝑓𝑈

K 𝑋>𝑈𝑒>𝑈(1 − 𝑡>𝑈) − K 𝑋𝑈>𝑒𝑈>(1 − 𝑡𝑈>) = 𝑓𝑈 ∀𝑖 ∈ 𝑁

> :(>,𝑈)∈𝐴 > :(𝑈,>)∈𝐴

K 𝑋>𝐽𝑒>𝐽s1 − 𝑡>𝐽t − K 𝑋𝐽>𝑒𝐽>s1 − 𝑡𝐽>t = 1,665.31 ∀𝑖 ∈ 𝑁

>:(>,𝐽)∈𝐴 >:(𝐽,>)∈𝐴

K 𝑋>𝐸𝑒>𝐸(1 − 𝑡>𝐸) − K 𝑋𝐸>𝑒𝐸>(1 − 𝑡𝐸>) = 6 ∀𝑖 ∈ 𝑁

>:(>,𝐸)∈𝐴 >:(𝐸,>)∈𝐴

K 𝑋>𝐶𝑒>𝐶(1 − 𝑡>𝐶) − K 𝑋𝐶>𝑒𝐶>(1 − 𝑡𝐶>) = 30 ∀𝑖 ∈ 𝑁

>:(>,𝐶)∈𝐴 >:(𝐶,>)∈𝐴

K 𝑋>j𝑒>js1 − 𝑡>jt − K 𝑋j>𝑒j>s1 − 𝑡j>t = 0 ∀𝑖, 𝑗 ∈ 𝑁\{𝐽, 𝐸, 𝐶, 𝑈}

>:(>,j)∈𝐴

>:(j,>)∈𝐴

𝑋>j ≥ 0 ∀𝑖, 𝑗 ∈ 𝑁

**3)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Node | Out | In | Out - In |  | f |
| USD | 0.0 | 52.8 | -52.8 | = | -52.8 |
| AUD | 0.0 | 0.0 | 0.0 | = | 0.0 |
| GBP | 0.0 | 0.0 | 0.0 | = | 0.0 |
| EUR | 6.0 | 0.0 | 6.0 | = | 6.0 |
| INR | 2205.8 | 2205.8 | 0.0 | = | 0.0 |
| JPY | 1665.3 | 0.0 | 1665.3 | = | 1665.3 |
| SGD | 71.4 | 71.4 | 0.0 | = | 0.0 |
| CHF | 30.0 | 0.0 | 30.0 | = | 30.0 |

Objective 52.77

The optimal solution results in **52.77** million USD, OB&A gains 0.04 million USD by using this conversion strategy.

**4)**

Objective function:

Constraints :

𝑀𝑎𝑥 − 𝑓𝑈

K 𝑋>𝑈𝑒>𝑈(1 − 𝑡>𝑈) − K 𝑋𝑈>𝑒𝑈>(1 − 𝑡𝑈>) = 𝑓𝑈 ∀𝑖 ∈ 𝑁

> :(>,𝑈)∈𝐴 > :(𝑈,>)∈𝐴

K 𝑋>𝐽𝑒>𝐽s1 − 𝑡>𝐽t − K 𝑋𝐽>𝑒𝐽>s1 − 𝑡𝐽>t = 1,665.31 ∀𝑖 ∈ 𝑁

>:(>,𝐽)∈𝐴 >:(𝐽,>)∈𝐴

K 𝑋>𝐸𝑒>𝐸(1 − 𝑡>𝐸) − K 𝑋𝐸>𝑒𝐸>(1 − 𝑡𝐸>) = 6 ∀𝑖 ∈ 𝑁

>:(>,𝐸)∈𝐴 >:(𝐸,>)∈𝐴

K 𝑋>𝐶𝑒>𝐶(1 − 𝑡>𝐶) − K 𝑋𝐶>𝑒𝐶>(1 − 𝑡𝐶>) = 30 ∀𝑖 ∈ 𝑁

>:(>,𝐶)∈𝐴 >:(𝐶,>)∈𝐴

K 𝑋>𝐴𝑒>𝐴(1 − 𝑡>𝐴) − K 𝑋𝐴>𝑒𝐴>(1 − 𝑡𝐴>) = −5 ∀𝑖 ∈ 𝑁

>:(>,𝐴)∈𝐴 >:(𝐴,>)∈𝐴

K 𝑋>j𝑒>js1 − 𝑡>jt − K 𝑋j>𝑒j>s1 − 𝑡j>t = 0 ∀𝑖, 𝑗 ∈ 𝑁\{𝐽, 𝐸, 𝐶, 𝑈, 𝐴}

>:(>,j)∈𝐴

>:(j,>)∈𝐴

𝑋>j ≥ 0 ∀𝑖, 𝑗 ∈ 𝑁

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Node | Out | In | Out - In |  | f |
| USD | 0.00 | 49.28 | -49.28 | = | -49.28 |
| AUD | 0.00 | 5.00 | -5.00 | = | -5.00 |
| GBP | 0.00 | 0.00 | 0.00 | = | 0.00 |
| EUR | 6.00 | 0.00 | 6.00 | = | 6.00 |
| INR | 2205.81 | 2205.81 | 0.00 | = | 0.00 |
| JPY | 1665.31 | 0.00 | 1665.31 | = | 1665.31 |
| SGD | 66.64 | 66.64 | 0.00 | = | 0.00 |
| CHF | 30.00 | 0.00 | 30.00 | = | 30.00 |

Objective 49.28

The optimal solution results in **49.28 million USD** if OB&A were to keep 5 million AUD.

# Problem 3: Coal Procurement at American Coal Power 1)

Indices:

𝑖 ∈ 𝐼 = {𝑃1, 𝑃2, 𝑃3, 𝑃4, 𝑃5} : Different production plants

𝑗 ∈ 𝐽 = {𝑀1, 𝑀2, 𝑀3, 𝑀4, 𝑀5, 𝑀6, 𝑀7, 𝑀8 − 𝐹, 𝑀8 − 𝑉} : Different mining companies

Parameters:

𝑝>: 𝑃𝑟𝑜𝑑𝑢𝑐𝑡𝑖𝑜𝑛 𝑑𝑒𝑚𝑎𝑛𝑑 𝑎𝑡 𝑝𝑙𝑎𝑛𝑡 𝑖 (𝐺𝑊ℎ) ℎ>: 𝐻𝑒𝑎𝑡 𝑟𝑎𝑡𝑒 𝑎𝑡 𝑝𝑙𝑎𝑛𝑡 𝑖 (𝐵𝑇𝑈𝑠/𝑘𝑊ℎ)

𝑘j: 𝐶𝑎𝑝𝑎𝑐𝑖𝑡𝑦 𝑎𝑡 𝑐𝑜𝑚𝑝𝑎𝑛𝑦 𝑗 (𝑡𝑜𝑛𝑠)

𝑐j: 𝐶𝑜𝑎𝑙 𝑐𝑜𝑠𝑡 𝑎𝑡 𝑐𝑜𝑚𝑝𝑎𝑛𝑦 𝑗 ($/𝑡𝑜𝑛)

𝑒j: 𝐸𝑛𝑒𝑟𝑔𝑦 𝑐𝑜𝑛𝑡𝑒𝑛𝑡 𝑜𝑓 𝑐𝑜𝑎𝑙 𝑎𝑡 𝑐𝑜𝑚𝑝𝑎𝑛𝑦 𝑗 (𝐵𝑇𝑈𝑠/𝑡𝑜𝑛)

𝑠j: 𝑆𝑢𝑙𝑝ℎ𝑢𝑟 𝑐𝑜𝑛𝑡𝑒𝑛𝑡 𝑜𝑓 𝑐𝑜𝑎𝑙 𝑎𝑡 𝑐𝑜𝑚𝑝𝑎𝑛𝑦 𝑗 (%)

𝑡>j: 𝑇𝑟𝑎𝑛𝑠𝑝𝑜𝑟𝑡𝑎𝑡𝑖𝑜𝑛 𝑐𝑜𝑠𝑡 𝑓𝑟𝑜𝑚 𝑐𝑜𝑚𝑝𝑎𝑛𝑦 𝑗 𝑡𝑜 𝑝𝑙𝑎𝑛𝑡 𝑖 ($/𝑡𝑜𝑛)

𝑎>j: 𝐴𝑑𝑑 − 𝑜𝑛 𝑐𝑜𝑠𝑡 𝑓𝑟𝑜𝑚 𝑐𝑜𝑚𝑝𝑎𝑛𝑦 𝑗 𝑡𝑜 𝑝𝑙𝑎𝑛𝑡 𝑖 ($/𝑡𝑜𝑛)

Decision variables:

𝑋>j: 𝐴𝑚𝑜𝑢𝑛𝑡 𝑜𝑓 𝑝𝑢𝑟𝑐ℎ𝑎𝑠𝑒𝑑 𝑐𝑜𝑎𝑙 𝑓𝑟𝑜𝑚 𝑐𝑜𝑚𝑝𝑎𝑛𝑦 𝑗 𝑓𝑜𝑟 𝑝𝑙𝑎𝑛𝑡 𝑖 (𝑡𝑜𝑛𝑠)

𝑍>j: 𝑃𝑟𝑜𝑑𝑢𝑐𝑡𝑖𝑜𝑛 𝑜𝑓 𝑒𝑛𝑒𝑟𝑔𝑦 𝑎𝑡 𝑝𝑙𝑎𝑛𝑡 𝑖 𝑝𝑒𝑟 𝑝𝑢𝑟𝑐ℎ𝑎𝑠𝑒𝑑 𝑐𝑜𝑎𝑙 𝑎𝑡 𝑝𝑙𝑎𝑛𝑡 𝑗 (𝐺𝑊ℎ)

𝑌 = É1 𝑖𝑓 𝑐𝑜𝑎𝑙 𝑖𝑠 𝑝𝑢𝑟𝑐ℎ𝑎𝑠𝑒𝑑 𝑎𝑡 𝑐𝑜𝑚𝑝𝑎𝑛𝑦 𝑗

j

0 𝑜𝑡ℎ𝑒𝑟𝑤𝑖𝑠𝑒

Objective function:

𝑀𝑖𝑛 K K 𝑐j𝑋>j + K K(𝑡>j + 𝑎>j)𝑋>j

j∈𝐽

>∈𝐼

j∈𝐽

>∈𝐼

Constraints:

1 1

𝑍>j = 𝑋>j𝑒j( )( )

(Production formula based on purchased coal)

ℎ>

K 𝑋>j ≤ 𝑌j𝑘j ,

>∈𝐼

1,000,000

(Capacity of variable tonnage companies)

∀𝑗 ∈ {𝑀4, 𝑀5, 𝑀6, 𝑀7, 𝑀8 − 𝑉}

K 𝑋>j = 𝑌j𝑘j ,

>∈𝐼

∀𝑗 ∈ {𝑀1, 𝑀2, 𝑀3, 𝑀8 − 𝐹}

K 𝑠> K 𝑋>j ≤ 0.025 K K 𝑋>j

(Capacity of fixed tonnage companies)

(2.5% max content of sulphur per plant)

>∈𝐼

j∈𝐽

>∈𝐼

j∈𝐽

K 𝑍>j = 𝑝> ∀𝑖 ∈ 𝐼 (Production demand)

j∈𝐽

Applying this model resulted in the following amounts of coal being purchased from company j for production plant i:

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Xij purchased coal (ton) | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8-F | M8-V | Total |
| P1 | 0 | 132955 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 132955 |
| P2 | 0 | 94697 | 12351 | 0 | 0 | 0 | 0 | 0 | 12351 | 119398 |
| P3 | 0 | 0 | 87649 | 0 | 0 | 0 | 0 | 0 | 87649 | 175299 |
| P4 | 0 | 62500 | 0 | 0 | 0 | 0 | 0 | 0 | 154715 | 217215 |
| P5 | 300000 | 9848 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 309848 |
| Total | 300000 | 300000 | 100000 | 0 | 0 | 0 | 0 | 0 | 254715 |  |

Resulting in a total cost of **$33,451,758**

1. To consider the constraint that ACP can only purchase from M8-V if a fixed amount of 400,000 tons from M8-F is purchased, we added this constraint to the model:

𝑌𝑀8–𝑉 ≤ 𝑌𝑀8–𝐹

Adding this constraint changed the distribution of purchases into the following way:

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Xij purchased coal (ton) | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8-F | M8-V | Total |
| P1 | 0 | 0 | 69920 | 0 | 0 | 0 | 0 | 0 | 69920 | 139841 |
| P2 | 0 | 0 | 24900 | 0 | 0 | 0 | 0 | 0 | 100917 | 125817 |
| P3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 173032 | 5830 | 178862 |
| P4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 221789 | 0 | 221789 |
| P5 | 300000 | 0 | 5179 | 0 | 0 | 0 | 0 | 5179 | 0 | 310359 |
| Total | 300000 | 0 | 100000 | 0 | 0 | 0 | 0 | 400000 | 176667 |  |

Resulting in a total cost of **$34,804,422** , which is $1,352,664 greater than the strategy in 1).

1. To consider the constraint that ACP would like to impose that if variable-tonnage contracts need to be used, at least four variable-tonnage contracts should be signed. To do so, the following variable and constraints were added to the model:

𝑉 = É1 𝑖𝑓4 𝑜𝑟 5 𝑣𝑎𝑟𝑖𝑎𝑏𝑙𝑒 − 𝑡𝑜𝑛𝑛𝑎𝑔𝑒 𝑐𝑜𝑛𝑡𝑟𝑎𝑐𝑡𝑠 𝑎𝑟𝑒 𝑠𝑖𝑔𝑛𝑒𝑑

0 𝑜𝑡ℎ𝑒𝑟𝑤𝑖𝑠𝑒

4𝑉 ≤ K 𝑌j ≤ 5𝑉 ,

j∈𝐽

∀𝑗 ∈ {𝑀4, 𝑀5, 𝑀6, 𝑀7, 𝑀8 − 𝑉}

𝑌j ≤ 𝑀 K 𝑋>j ,

>∈𝐼

∀𝑗 ∈ 𝑀4, 𝑀5, 𝑀6, 𝑀7, 𝑀8 − 𝑉

(to force the number of variable-tonnage contracts to be 4, 5 or 0)

where M is a significantly large value

(to force a purchase at company j if Yj is equal to 1)

These changes to the model lead to the following purchase strategy:

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Xij purchased coal (ton) | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8-F | M8-V | Total |
| P1 | 0 | 0 | 69920 | 0.00000 | 0.00000 | 0.00000 | 0 | 0 | 69920 | 139841 |
| P2 | 0 | 0 | 24900 | 0.00000 | 0.00000 | 0.00000 | 0 | 0 | 100917 | 125817 |
| P3 | 0 | 0 | 0 | 0.00001 | 0.00000 | 0.00001 | 0 | 178211 | 650 | 178862 |
| P4 | 0 | 0 | 0 | 0.00000 | 0.00001 | 0.00000 | 0 | 221789 | 0 | 221789 |
| P5 | 300000 | 0 | 5179 | 0.00000 | 0.00000 | 0.00000 | 0 | 0 | 5179 | 310359 |
| Total | 300000 | 0 | 100000 | 0.00001 | 0.00001 | 0.00001 | 0 | 400000 | 176667 |  |

Resulting in a total cost of **$34,804,422,** which is not different from the result in 2). We believe that it is more beneficial to include M8-V than to not include any variable-tonnage contracts, therefore the optimal solution is to purchase very small amounts in the other variable-tonnage companies in order to respect the constraint that if variable-tonnage contracts are signed, at least four variable-tonnage companies must be signed.