OOPS MIDDLE MILE PLANNING CONSULTING REPORT

Middle Mile Logistics

Produced By: ISEN Consulting Firm Team 12

Ajaya Harish Chandra Kumar (UIN: 133007163)
Chirag Anantha (UIN: 833003133)
Ishank Gupta (UIN: 832000398)
Suman Singh (UIN: 232009058)

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1.0 Executive Summary

The purpose of this consulting report is to present a fully optimal model for Oops (an E-commerce Company) that reduces the cost of the company while transporting packages between Oops shipping centers. With the rapidly growing digital world, E-commerce has emerged as a major option for everyone to buy and sell any product, right from all basic needs to specific need categories. With the growing demand for shopping through E-commerce, shipping companies have been facing issues in different sectors to fulfill customer requirements on time, and generating adequate margins for the company has become a critical thinking topic. The same problem is being faced by our client - “Oops” and hence the company wants to reduce the overall cost of shipping by getting optimal solutions on package assignment to vehicles, the number, and types of vehicles assigned to shipping centers, and the number of operators to be relocated from one shipping center to another.

From the information provided, the ISEN consulting firm has built a Mixed Integer Linear Programming (MILP) to optimize the Oops Middle Mile Logistics problem and reduce the overall cost. Reducing the total cost involves reducing transportation costs (operating cost of vehicles), operator relocation costs (proportional to relocation distance), and package costs (if delayed). With the given parameters of package, vehicle, operator, trip/shipping, and shipping center, variables are defined and objective functions & constraints are developed to minimize the overall cost. The overall process of this project was divided into two phases. Phase 1 involved the creation of the Mixed Integer Linear Programming model. This model was developed taking into account a list of worded constraints provided by Oops. Section 2.3 gives a total list of the worded constraints given by Oops. Phase 2 of the project involved solving the model with the data given by Oops and performing sensitivity analysis on the solution to answer the what if questions of Oops.

After Phase 1, we carefully reviewed our original model and found out the need to make necessary improvements. The model was working well for small scale problems but it took a lot of time to solve large scale problems in the order of few hundred packages and it was identified that some of the constraints we had developed mathematically were not completely correct. With this being said the Phase 2 model present in section 3.0 is the final model that Oops should use to solve their middle mile logistics problem. This model is simple, robust and can give the results of the large-scale problems in a matter of few seconds. Section 3.1, 3.2, 3.3 and 3.4 gives a detailed explanation of the changed model.

ISEN consulting firm has split Phase 2 of this project into two main components, first component being the final optimal objective value derived from the data provided directly from Oops and the second component being Solution Analysis. The final solution can be found within section 4.0. This section provides a detailed explanation on how the solution was calculated via AMPL and presents the lowest cost that can be achieved, number and type of vehicle operated from one shipping centre to another, number of operators that need to be relocated, base and relocated shipping centre of the relocated operator, packages that are late and which package should be loaded in which vehicle. For the given operating conditions, Oops should expect a total cost of $39008 for their middle mile logistics. While this value seems relatively large, it is the smallest value that could satisfy all the constraints and parameters that Oops has provided.

In the second component of Phase 2, we analysed the solution. This analysis was carried out by changing the data or sometimes even the model to answer the what if questions provided to us by Oops. The answers to the what if questions given by Oops management is answered in section 5.0. In addition to the what if questions given by Oops, our firm developed certain scenarios by changing the data, model or both to provide answers to how the objective value might change for some real-world problems.

In conclusion the ISEN Consulting Firm provides Oops with a MILP model that will solve their middle mile logistics problem at the lowest possible cost. The final solution gives insight into the costs and the operating conditions given by the model to minimize the total cost of middle mile, and the solution analysis provides Oops with adaptability to meet changing needs in an always changing dynamics of the e-commerce industry. If Oops chooses to adopt the model in this report, the ISEN Consulting Firm can assure that for the given operating conditions, Oops will be able to achieve the most efficient middle mile logistics planning in the e-commerce industry.

2.0 Introduction

This part of the report will give a background on the problem, a brief introduction to middle-mile logistics, the problem statement, and the assumptions made to develop the Mixed Integer Linear Programming model.

2.1 Background

The world has changed, so have the people and so has the technology. The whole market is moving towards digitization. The development in the sector of web tools has made people's life much easier than before, and also the covid pandemic has made a significant impact on the living style of people around the world. These days most people avoid going outside for the purpose of shopping, instead, they prefer to leverage the advancements made in E-commerce and use applications/websites on their smartphones or computers to shop for things they want from the comfort of their homes.

Fig 1: Growth of E-Commerce in the US

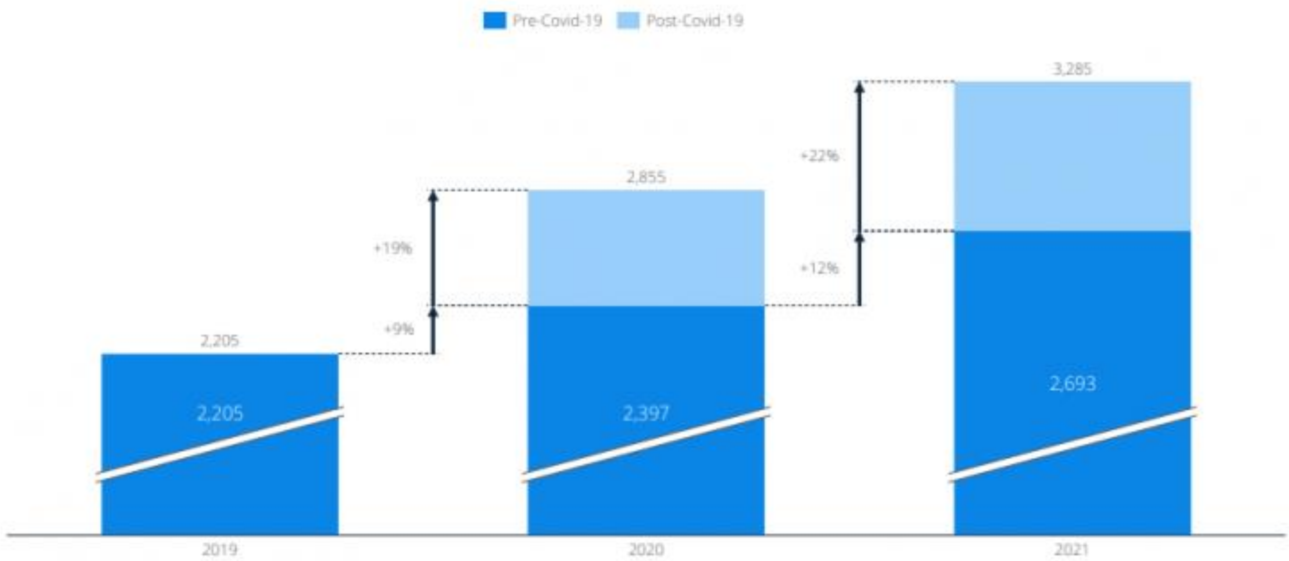

Fig 2: Impact of Covid on E-Commerce growth

With the emergence of E-commerce companies, customers now have a wide variety to choose from which in turn has increased the competition among E-commerce companies. E-commerce companies now must be highly efficient in every part of their operations to make better profits and survive in the market. Oops is one such company that has decided to optimize its middle-mile logistics and make it more cost-efficient.

2.2 Middle Mile Logistics

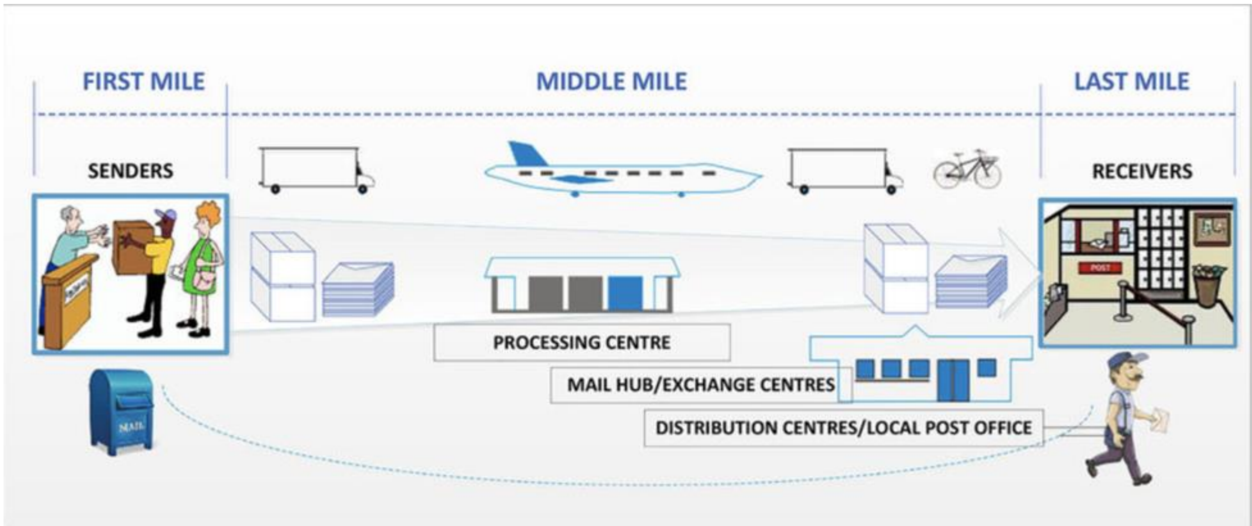

Fig 3: General overview of Middle Mile Logistics

The middle mile delivery stage of the supply chain is when products are moved between facilities before being picked up for delivery. A middle-mile delivery often takes a path from a holding or fulfillment center to a distribution hub.

The procedures required for middle-mile delivery are referred to as middle-mile logistics. It involves working with vehicles to transport goods between the two locations. Planning and scheduling for middle-mile deliveries must consider driver availability, order load, and other considerations.

2.3 Problem Statement

Oops targets the luxury market. While its prices are higher, it guarantees that products/packages will be delivered on or before a given deadline (measured in hours) or the product is free. Oops wants to optimize its Middle Mile Logistics by reducing the cost incurred in the Middle Mile. The total cost incurred in Middle Mile Logistics for Oops is made up of the operating cost of vehicles, relocation cost of operators, and the cost of the package if delivered late. There are certain parameters and operating constraints given by Oops to ISEN consulting firm which have to be taken into account while developing the Mixed Integer Linear Programming model. They are:

Package info:

For each package, Oops provides the ISEN consulting firm with its origin shipping center, destination shipping center, weight, the time limit to reach its destination shipping center, cost, and the shipping incompatibilities of the packages (if two packages are incompatible, the packages must not travel in the same vehicle even if they are going from the same origin center to same destination center).

Vehicle info:

ISEN consulting firm will be given the number of trucks, planes, and trains present in the central depot that can be used for Middle-Mile logistics. Oops also provides the maximum weight capacity and speed of each vehicle type.

Operator info:

Oops hires highly versatile operators so every operator can operate any vehicle. ISEN consulting firm will be given the number of operators living near each shipping center. In case an operator is to be relocated from his/her home shipping center to another shipping center due to operational demands, the operator must be paid a bonus, proportional to the relocation distance. The relocation cost per mile for the operator will also be given.

Trip/Shipping info:

Oops strictly adheres to the maximum weight capacity of the vehicle and no vehicle can be overloaded. It also strictly advises against loading incompatible packages in the same vehicle. Oops has fixed the operational cost per mile of each vehicle type and this value must be used to calculate the operating cost of vehicles.

Shipping center info:

ISEN consulting firm will be given the maximum number of vehicles (independent of vehicle types) that can be loaded or unloaded in a particular shipping center which is set by labor unions.

2.4 Assumptions

- The allocation of vehicles from the depot to shipping centers is instantaneous at the beginning of the day.
- The relocation of operators from their home shipping centers to other shipping centers is instantaneous at the beginning of the day.
- Each vehicle starts at one shipping center and goes directly to the destination shipping center. That is, vehicles will not make intermediate loading/unloading stops.
- The loading and unloading of vehicles happen instantaneously.
- The distance between shipping centers is the same irrespective of the vehicle type (as the distance between point A to point B may be different when traveling via road, rail or plane).

3.0 Methodology

This section presents the improved MILP model made after careful review of the model from phase 1 of the project. The detailed explanation of parameters, decision variables chosen, objective function developed and how the model is constrained to the given operating conditions of Oops is given in this section.

3.1 Decision Variables

These are the variables representing the various decisions that model will make to create the Middle Mile Logistics system for Oops.

x_{pv} - Binary variable to determine whether package p is shipped in vehicle v

y_{vij} - Binary variable determining whether vehicle v goes from location i to j

z_{ij} - Number of operators relocated from location i to j

T_p - Binary variable to determine whether the package is tardy (not on time)

3.2 Parameters

The following Parameters have been considered based on the problem defined by OOPS:

L: Number of shipping locations

P: Number of packages to be shipped

V: Number of vehicles available

K: Number of incompatible pair of packages

I_{kr}: ID of package r of the k^{th} incompatible pair; for r =1,2 for k =1..K

w_p: Weight of package p

s_p: Origin of package p

e_p: Destination of package p

f_p: Maximum transit time for package p

cl_p: Penalty/Cost if package p is late

h_v: Weight capacity of vehicle v

b_v: Vehicle type (truck, plane or train) of vehicle v

a_i: Number of operators whose home base is location i

l_i: Maximum number of vehicles that can be loaded at location i

u_i: Maximum number of vehicles that can be unloaded at location j

cm_{ij}: Cost of relocation one operator from location i to j

t_{vij}: Transit time from location i to j using vehicle v

co_{vij}: Cost of operating vehicle v from location i to j

3.3 Objective Function

The objective is to ensure that all the packages are delivered to the correct locations while ensuring all the demands/restriction that Oops has defined at the minimum cost.

min cost: $\sum_{p=1}^{P} cl_p T_p + \sum_{v=1}^{V}\sum_{i=1}^{L}\sum_{j=1}^{L} co_{vij} * y_{vij} + \sum_{i=1}^{L}\sum_{j=1}^{L} cm_{ij} * Z_{ij}$

The first part of the objective functions is required to add the cost incurred on the company if the package is late. The second part is the operating cost of vehicle. Here a binary variable "y" is used to ensure that only the cost of vehicles being used is added to the total cost. The third part is the operator relocation cost. Here a variable z is used to count the number of operators relocated from a particular base location "i" to destination location "j". This variable "z" is multiplied by the relocation cost obtained by multiplying the relocation cost per mile and distance.

3.4 Constraints

3.4.1 C1: Packages can only be shipped with one vehicle, and all packages are shipped

This constraint ensures that each package is assigned to at most 1 vehicle only and furthermore also ensures that each package is shipped (as it's assigned to a vehicle). This constraint works as follows: LHS: $x_{p,1} + x_{p.,2} + \ldots.. x_{p,v} = 1$ this ensures that for each package "p" only 1 vehicle out of "V" vehicles is assigned. Also, furthermore, since each package is assigned a vehicle so this by default also ensures that the package is shipped.

$$\sum_{v=1}^{V} x_{pv} = 1 \qquad\qquad (p=1..P)$$

3.4.2 C2: Vehicle can only travel on one route

This constraint ensures that each vehicle is restricted to moving on one single route only i.e., once it leaves a starting center it will directly go to the destination center and won't be used again for a different route. This constraint works as follows:

LHS: for each vehicle "v" we sum it up for all the routes that can exist in our problem where one route means going from "i" to particular "j". So, for each vehicle v, we are summing over "i" and "j" and ensuring that it is less than or equal to one. It's either "<" or "=" because not all vehicles available in the model will be assigned packages and thus won't be used. And "=" is used to ensure that those vehicles "v" which are being used are assigned to only 1 route (going from specific "i" to specific "j").

$$\sum_{i=1}^{L} \sum_{j=1}^{L} y_{vij} \leq 1 \qquad\qquad (v=1..V)$$

3.4.3 C3: Packages must be shipped on a vehicle that is going from their origin to their destination

This constraint is used to ensure that a package is allocated to a vehicle that is going from the package's starting center to the destination center.
There can be 2 cases in this constraint:

a) If $x_{p,v}$ is equal to 1, i.e., a package "p" is assigned to a vehicle "v" then that vehicle "v" will be assigned to the route which is going from the package's origin point and package destination centers.
b) If $x_{p,v}$ is 0, which implies that package "p" is not assigned to vehicle "v" then vehicle $y_{v,e[p],s[p]}$ has a choice if it still takes value 1 implies that it's going on that route maybe because of some other package and another option is 0 which means not being assigned to that route.

$$x_{pv} \leq y_{vs_pe_p} \qquad (p=1..P,\ v=1..V)$$

3.4.4 C4: Packages must reach their destination within the time limit if shipped without penalty

This constraint is used to determine which packages are tardy (delivered beyond their target time). How this constraint works is that, if the package assigned to vehicle "v" going from "i" to "j" is taking more time to deliver than the package's target time (as specified by the business conditions) then T_p will be set to 1 and package will be considered Tardy. This constraint works as follows:
LHS: Calculates the time it takes to for each package p to deliver.
($x_{p,v}$*$t_{v,s[p],e[p]}$) so based on previous constraints we are restricting each part to a particular vehicle "v" only. For example, if package 1 is going from center 1 to center 2 and 4 vehicles only are available then:
LHS: $X_{1,1}$*$t_{1,1,2}$+ $X_{1,2}$*$t_{2,1,2}$+$X_{1,3}$*$t_{1,1,2}$+ $X_{1,4}$*$t_{1,1,2}$ (also as we know that a particular package can be assigned to one vehicle only so for only one out of $x_{1,1}$,$x_{1,2}$,$x_{1,3}$,$x_{1,4}$ Will be assigned as 1 and rest 0 (assuming vehicle 1 for explanation is assigned).
2 cases possible:

a) if $x_{1,1}$*$T_{1,1,2}$ is > f_1, then to ensure that the constraint is valid T_1 will be set to 1 (PACKAGE IS TARDY) and our M (can be set as maximum $T_{v,I,j}$ value available) will be included in the constraint to make sure that M+f_1 is >= $x_{1,1}$*$T_{1,1,2}$
b) if $x_{1,1}$*$T_{1,1,2}$ is <= $f_{1,}$ then as the constraint is already holding up, T_p will be set to 0 (Package not tardy).

$$\sum_{v=1}^{V} \sum_{i=1}^{L} \sum_{j=1}^{L} t_{vij} * x_{pv} \leq f_p + M * T_p \qquad (p=1..P)$$

3.4.5 C5: Each location can't exceed the limit on loading per day

This constraint is to ensure the union labor requirements that only a certain number of trucks can be loaded in each shipping centre. This constraint works as follows:
LHS: Calculates the total vehicles that is starting from a shipping centre and ensures it is less than or equal to the maximum value given by Oops.

$$\sum_{j=1}^{L} \sum_{v=1}^{V} y_{vij} \leq l_i \qquad (i=1..L)$$

3.4.6 C6: Each location can't exceed the limit on unloading per day

This constraint is to ensure the union labor requirements that only a certain number of trucks can be unloaded in each shipping centre. This constraint works as follows:
LHS: Calculates the total vehicles that is reaching a shipping centre and ensures it is less or equal to the maximum value given by Oops.

$$\sum_{i=1}^{L} \sum_{v=1}^{V} y_{vij} \leq u_j \qquad (j=1..L)$$

3.4.7 C7: Incompatible packages each need a separate vehicle

As specified by OOPS that some of the packages are incompatible with each other for safety reasons and thus be assigned to different vehicles. This constraint work as follows:

If a package is incompatible with the second package in the k^{th} pair of incompatible packages, then the they cannot be loaded on the same vehicle.

$$x_{I_{k1},v} + x_{I_{k}2,v} \leq 1 \qquad\qquad (k=1..K, v=1..V)$$

3.4.8 C8: Cannot exceed the number of operators available in each location

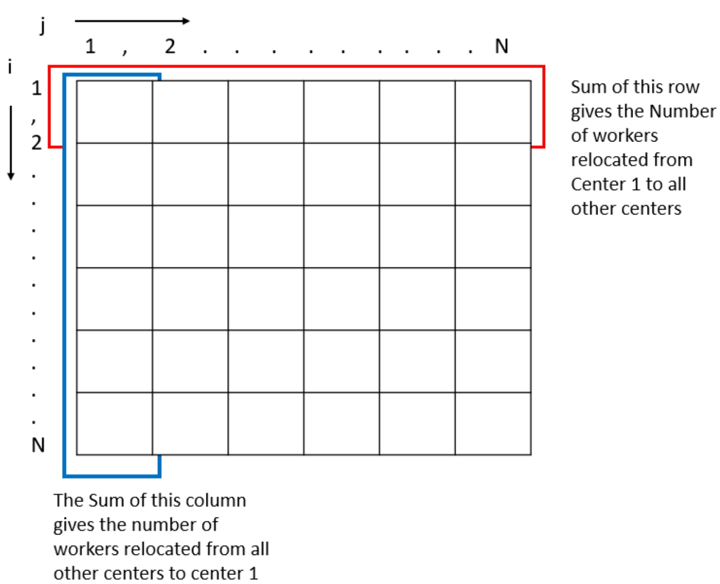

Fig 4: Relocation of operators

This constraint is added to make sure that each center has enough number of workers (including both original workers present + number of workers relocated from other centers to this center) should be sufficient to handle all the vehicles (irrespective of type) assigned to that center. So, for each center we are calculating:

LHS, ($y_{v,i,j}$) (Number of vehicles allocated at center i) + $\sum_{j=1}^{N} Z_{ij}$ (Number of workers relocated from center "i" to other centers – the row (marked by the red box in figure) - $\sum_{j=1}^{N} Z_{ji}$ (Number or workers relocated from other centers to center "i" - the column (marked by the blue box) in the figure) <= RHS, the original number of workers available at each center "i".

$$\sum_{j=1}^{L}\sum_{v=1}^{V} y_{vij} + \sum_{j=1}^{L} Z_{ij} - \sum_{j=1}^{L} Z_{ji} \leq a_i \qquad (i=1..L)$$

3.4.9 C9: Packages cannot exceed the vehicle weight

This constraint is to ensure that packages are assigned to vehicles in such a way that the sum of the weights of packages does not exceed the vehicle capacity. For every vehicle, we are ensuring that sum of the weight of all packages allocated to it ($x_{p,v}$*w_p so for package p is if its allocated to v then $x_{p,v}$ will be 1 and that package weight will be considered but if package p is not going via vehicle v then $x_{p,v} = 0$ and that packages weight not considered.) is less than equal to weight limit of each vehicle(specified by parameter h).

$$\sum_{p=1}^{P} w_p * x_{pv} \leq h_v \qquad (v=1..V)$$

3.4.10 C10: Non-Negativity

This constraint is to ensure that all the non-binary variables are positive only.

$$z_{ij} \geq 0 \qquad (i=1..L, j=1..L)$$

3.4.11 C11: Integrality Constraint

This constraint is to ensure that all the non-binary variables are integers only.

$$z_{ij} \text{ is an integer} \qquad (i=1..L, j=1..L)$$

3.4.12 C12: Binary Requirement

This constraint is added to make sure whether the resources are utilized at full or not utilized at all. For example, no vehicle can be utilized in half or half of a package cannot be loaded in a vehicle.

x_{pv} is binary (p=1..P, v=1..V)

y_{vij} is binary (v=1..V, i=1..L, j=1..L)

T_p is binary (p=1..P)

4.0 Solution

This section of the report gives an overview of the data given by Oops and a brief explanation of the solution when we solved the model for the given data using AMPL.

4.1 Given Parameters

After phase 1 of the project, our consulting firm was given the data to get the optimal solution and to perform the sensitivity analysis on the results.

4.1.1 Vehicle Information

Vehicle Information consists of the types of vehicles and their count available with Oops, the maximum weight capacity of each vehicle type, the maximum speed of each vehicle type and the operating cost of each vehicle type.

		Capacity	Speed	Operating
Type	Count	(Kilograms)	(Miles/minute)	($/mile)
Trucks	96	1200	1	1
Planes	12	600	3	50
Trains	12	6000	2	10

Table 1: Vehicle information

4.1.2 Warehouse Information

Warehouse Information consists of the number and distances between each warehouse. Oops has a total of 10 warehouses and the distance in miles between each warehouse is given in the table below.

Distances	1	2	3	4	5	6	7	8	9	10
1	0	181	93	83	111	70	165	204	86	142
2	181	0	169	105	101	115	81	36	101	114
3	93	169	0	120	67	74	195	202	78	190
4	83	105	120	0	83	46	84	123	50	70
5	111	101	67	83	0	47	139	135	34	145

6	70	115	74	46	47	0	122	143	17	116
7	165	81	195	84	139	122	0	70	117	41
8	204	36	202	123	135	143	70	0	131	110
9	86	101	78	50	34	17	117	131	0	116
10	142	114	190	70	145	116	41	110	116	0

Table 2a: Warehouse information

Warehouse ID	No. Drivers	Load Limit	Unload Limit
1	12	16	12
2	13	13	12
3	10	16	15
4	11	14	14
5	14	15	15
6	13	14	16
7	8	14	12
8	11	16	12
9	13	13	13
10	11	15	16

Table 2b: Warehouse information

4.1.3 Package Information

Package Information consists of the package ID, weight of the package in kilograms, origin & destination shipping centre of the package, maximum transit time of the package and also the cost of the package which is incurred on the company if the package is late.

	Weight	Warehouses		Time Limit	Penalty Cost
Package ID	(Kilograms)	Origin	Destination	(Minutes)	(Dollars)
1	587	5	8	116	728
2	489	7	6	143	915
3	228	5	4	129	687
4	698	4	10	134	818
5	722	5	9	129	467
6	405	1	6	115	665
7	757	6	4	140	450

8	848	8	3	134	867
9	465	4	1	117	456
10	615	7	6	116	423
11	546	6	5	124	993
12	906	5	6	139	632
13	304	2	9	125	652
14	124	5	1	141	586
15	936	5	8	122	633
16	126	1	9	136	714
17	339	9	6	137	987
18	930	8	3	115	884
19	133	7	10	128	549
20	370	3	7	130	409
21	434	7	2	120	613
22	816	9	8	131	755
23	716	5	1	130	527
24	252	9	4	129	370
25	364	9	2	135	207
26	454	2	10	117	424
27	237	5	7	119	435
28	405	1	5	127	507
29	91	6	8	126	310
30	424	7	3	134	574
31	796	5	9	115	449
32	304	4	3	147	813
33	862	5	1	149	590
34	611	2	10	140	229
35	669	10	6	119	557
36	425	7	3	139	926
37	142	9	6	145	805
38	356	4	8	134	734
39	370	4	2	139	595
40	251	2	3	112	720
41	10	4	7	120	719
42	159	2	3	130	703
43	138	3	10	115	762
44	575	5	7	122	208
45	9	8	9	124	314
46	582	5	3	143	270

47	830	6	4	118	847
48	616	5	1	138	536
49	688	10	4	131	740
50	330	8	1	134	885
51	240	7	6	148	906
52	565	9	10	143	985
53	507	3	8	143	606
54	215	9	8	143	498
55	108	4	6	137	234
56	441	2	4	131	716
57	753	6	3	137	951
58	967	3	1	118	823
59	656	9	6	129	479
60	823	7	1	131	272
61	867	9	4	118	251
62	668	3	10	138	874
63	958	2	8	112	524
64	171	2	6	123	932
65	17	8	4	133	245
66	185	4	9	126	803
67	30	8	5	136	280
68	745	4	1	149	436
69	252	7	8	116	364
70	291	7	1	137	709
71	77	4	5	141	588
72	709	2	10	115	413
73	97	10	6	142	551
74	435	5	3	126	929
75	351	7	2	129	899
76	180	7	3	123	817
77	117	1	10	144	741
78	995	6	3	116	355
79	156	7	3	119	801
80	439	6	7	141	890
81	724	3	8	123	554
82	106	9	3	126	512
83	920	1	10	142	637
84	144	1	7	127	258
85	717	1	3	120	902

86	755	4	6	145	672
87	926	6	3	148	675
88	531	9	1	142	486
89	784	1	9	140	271
90	654	9	10	137	477
91	474	6	8	143	713
92	421	2	9	131	816
93	807	4	7	112	573
94	503	7	4	110	540
95	113	4	9	120	332
96	561	7	1	129	650
97	455	1	7	124	386
98	31	7	3	145	598
99	732	5	10	140	539
100	736	1	3	118	923
101	339	1	10	146	942
102	940	1	10	115	279
103	638	5	2	111	464
104	353	6	7	128	774
105	876	9	8	145	247
106	408	10	7	115	518
107	546	7	10	136	294
108	522	3	6	140	374
109	912	1	4	146	378
110	962	4	6	147	964
111	741	3	10	127	445
112	240	5	1	145	315
113	380	4	9	136	599
114	525	1	9	148	243
115	354	9	10	131	316
116	748	5	2	143	971
117	414	8	3	129	295
118	83	4	1	121	980
119	831	9	3	148	820
120	74	4	2	116	473
121	334	10	1	136	405
122	933	4	8	141	936
123	643	1	5	143	935
124	844	3	6	116	663

125	381	8	4	127	578
126	929	4	8	136	615
127	889	1	7	119	318
128	711	8	10	144	585
129	833	2	7	120	417
130	712	7	10	117	458
131	254	9	6	117	736
132	444	8	4	148	395
133	550	6	3	120	356
134	812	1	7	141	309
135	167	4	1	116	333
136	723	6	10	124	840
137	397	8	6	118	222
138	705	1	6	122	340
139	803	9	2	119	594
140	820	5	8	128	375
141	261	10	9	135	326
142	470	7	9	145	528
143	104	9	2	126	752
144	845	6	7	140	455
145	344	2	3	120	880
146	53	6	9	125	202
147	846	10	5	117	647
148	682	9	2	142	471
149	283	3	8	130	427
150	749	3	2	134	701
151	414	10	7	146	223
152	336	2	9	112	641
153	518	7	2	131	438
154	347	10	6	146	517
155	834	4	9	114	415
156	243	2	6	146	927
157	309	7	8	124	609
158	966	2	5	129	382
159	289	4	3	120	306
160	178	10	6	143	312
161	202	5	2	132	544
162	63	4	1	147	669
163	770	6	7	122	956

164	91	3	7	141	351
165	692	6	8	128	738
166	181	4	10	116	925
167	488	9	4	114	838
168	696	5	7	146	406
169	782	3	6	112	692
170	14	10	5	142	516
171	995	6	1	113	476
172	834	9	1	148	992
173	460	9	10	137	630
174	127	3	4	140	979
175	808	10	9	145	730
176	189	7	8	149	844
177	656	5	10	110	950
178	922	3	6	133	233
179	251	2	8	129	561
180	248	8	5	142	331

Table 3: Package information

4.1.4 Package Incompatibility Info

Package incompatibility Information consists of the pairs of packages which are incompatible and have to be shipped in different vehicles

package_1	package_2
41	93
30	79
76	98
1	15
77	83
38	126
77	101
22	54
27	44
108	178
53	81
118	162
75	153

8	117
34	72
115	173
66	113
108	124

Table 4: Package incompatibility information

4.1.5 Operator Info

The relocation cost of operators from one location to another is set at $2 per mile.

4.2 Results

ISEN consulting firm has made use of AMPL (gurobi solver) to solve the middle mile logistics problem and arrive at the optimal value. After receiving data from Oops, we developed both model file and the data file which are a must for AMPL. Please note that vehicle numbered from 1 to 96 are trucks, 97 to 108 are planes and 109 to 120 are trains.

```
File    Edit    View

#BigMformulation
param L;                #no. of shipping Locations
param P;                #no. of packages to shipped
param V;                                        #Total no. of vehicles available
param K;                                        #Number of incompatible pair of packages
param I{k in 1..K, r in 1..2};                  #ID of package r of the kth incompatible pair, for r=1,2 for k=1..K
param w{p in 1..P};                             #weight of package p
param s{p in 1..P};                             #origin of package p
param e{p in 1..P};                             #destination of package p
param f{p in 1..P};                             #maximum transit time for package p
param cl{p in 1..P};                            #penalty cost if package p is late
param h{v in 1..V};                             #weight capacity of vehicle v
param b{v in 1..V};                             #type of vehicle v
param a{i in 1..L};                             #no. of operators whose home base is location i
param l{i in 1..L};                             #maximum number of vehicle that can be loaded at location i
param u{i in 1..L};                             #maximum number of vehicles that can be loaded at location i
param cm{i in 1..L, j in 1..L};                 #cost of relocating operator from location i to location j
param t{v in 1..V, i in 1..L, j in 1..L};       #transit time from location i to j using vehicle v
param co{v in 1..V, i in 1..L, j in 1..L};      #cost of operating vehicle v from i to j
param M;

var x{p in 1..P, v in 1..V} binary;                 #Binary variable to determine whether package p is shipped in vehicle v
var y{v in 1..V, i in 1..L, j in 1..L} binary;      #Binary variable to determine whether vehicle v goes from location i to j
var z{i in 1..L, j in 1..L}>=0 integer;                     #number of operators relocated from i to j
var T{p in 1..P} binary;                                #Binary variable to determine whether package p is not on time

minimize Cost:
sum{p in 1..P}cl[p]*T[p] + sum{v in 1..V, i in 1..L, j in 1..L}co[v,i,j]*y[v,i,j] + sum{i in 1..L, j in 1..L}cm[i,j]*z[i,j];
subject to
Constraint1{p in 1..P}: sum{v in 1..V}x[p,v]=1;
Constraint2{v in 1..V}: sum{i in 1..L, j in 1..L}y[v,i,j]<=1;
Constraint3{p in 1..P, v in 1..V}: x[p,v]<=y[v,s[p],e[p]];
Constraint4{p in 1..P}: sum{v in 1..V}t[v,s[p],e[p]]*x[p,v]<=f[p]+M*T[p];
Constraint5{i in 1..L}: sum{j in 1..L, v in 1..V}y[v,i,j]<=l[i];
Constraint6{j in 1..L}: sum{i in 1..L, v in 1..V}y[v,i,j]<=u[j];
Constraint7{k in 1..K, v in 1..V}: x[I[k,1],v]+x[I[k,2],v]<=1;
Ln 10, Col 61                                      100%    Windows (CRLF)    UTF-8
```

Fig 5:AMPL Model File

```
param L:= 10; #Number of shipping centres
param P:= 180; #Number of packages to be shipped
param V:= 120; #Number of vehicle types
param K:= 18; #number of pairs of incompatible packages
param I: 1    2:=
      1  41  93
      2  30  79
      3  76  98
      4   1  15
      5  77  83
      6  38  126
      7  77  101
      8  22  54
      9  27  44
      10 108 178
      11 53  81
      12 118 162
      13 75  153
      14 8   117
      15 34  72
      16 115 173
      17 66  113
      18 108 124;
param w:=
1     587
2     489
3     228
4     698
5     722
6     405
7     757
8     848
9     465
10    615
11    546
```

Fig 6: AMPL Data File

4.2.1 Optimal Solution

For the given parameters and operating conditions, the least possible total cost for middle mile logistics of Oops is $39008.

```
sw: ampl
ampl: option solver gurobi;
ampl: reset;reset;
ampl: model Solution1Model.txt;
ampl: data Solution1Data.txt;
ampl: solve;
Gurobi 9.5.2: optimal solution; objective 39008
2103159 simplex iterations
14560 branch-and-cut nodes
ampl:
```

Fig 7: AMPL Solution

4.2.2 Package Assignment Information

The table below gives the details whether a package is Tardy or not and also the vehicle to which each package is allocated to. For the given operating conditions, a total of 25 packages are tardy.

```
File  Edit  Help
sw: ampl
ampl: option solver gurobi;
ampl: reset;reset;
ampl: model Solution1Model.txt;
ampl: data Solution1Data.txt;
ampl: solve;
Gurobi 9.5.2: optimal solution; objective 39008
2103159 simplex iterations
14560 branch-and-cut nodes
ampl: display T;
T [*] :=
  1 0    19 0    37 0    55 0    73 0    91 0   109 0   127 0   145 1   163 0
  2 0    20 1    38 0    56 0    74 0    92 0   110 0   128 0   146 0   164 1
  3 0    21 0    39 0    57 0    75 0    93 0   111 0   129 0   147 1   165 0
  4 0    22 0    40 1    58 0    76 0    94 0   112 0   130 0   148 0   166 0
  5 0    23 0    41 0    59 0    77 0    95 0   113 0   131 0   149 1   167 0
  6 0    24 0    42 1    60 0    78 0    96 0   114 0   132 0   150 1   168 0
  7 0    25 0    43 0    61 0    79 0    97 0   115 0   133 0   151 0   169 0
  8 1    26 0    44 1    62 0    80 0    98 1   116 0   134 0   152 0   170 1
  9 0    27 1    45 1    63 0    81 1    99 0   117 1   135 0   153 0   171 0
 10 1    28 0    46 0    64 0    82 0   100 0   118 0   136 0   154 0   172 0
 11 0    29 0    47 0    65 0    83 0   101 0   119 0   137 1   155 0   173 0
 12 0    30 1    48 0    66 0    84 0   102 1   120 0   138 0   156 0   174 0
 13 0    31 0    49 0    67 0    85 0   103 0   121 1   139 0   157 0   175 0
 14 0    32 0    50 1    68 0    86 0   104 0   122 0   140 0   158 0   176 0
 15 1    33 0    51 0    69 0    87 0   105 0   123 0   141 0   159 0   177 0
 16 0    34 0    52 0    70 0    88 0   106 0   124 0   142 0   160 0   178 0
 17 0    35 0    53 1    71 0    89 0   107 0   125 0   143 0   161 0   179 0
 18 1    36 0    54 0    72 0    90 0   108 0   126 0   144 0   162 0   180 0
;

ampl:
```

Fig 8: AMPL Output determining whether package is late or not

```
File  Edit  Help

ampl: display x;
x [*,*]
:     1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19 :=
1     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
3     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
4     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
5     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
6     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
7     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
8     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
9     0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
10    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
11    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
12    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
13    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
14    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
15    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
16    0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0
17    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
18    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
19    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
20    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
21    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
22    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
23    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
24    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
25    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
26    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
27    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
28    0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0
29    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
30    0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
31    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
32    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
```

Fig 9: AMPL output of Assignment of package to vehicles

Package Number	Package Late? Y/N	Package assigned to vehicle
1	N	110
2	N	64
3	N	44
4	N	88
5	N	25
6	N	52
7	N	57
8	Y	67
9	N	2
10	Y	27
11	N	70
12	N	62
13	N	48
14	N	114
15	Y	37
16	N	15
17	N	90
18	Y	40
19	N	75
20	Y	26
21	N	66
22	N	59
23	N	114
24	N	93
25	N	85
26	N	86
27	Y	23
28	N	5
29	N	111
30	Y	4
31	N	79
32	N	42
33	N	114
34	N	54
35	N	31
36	N	109
37	N	90

38	N	29
39	N	65
40	Y	83
41	N	38
42	Y	83
43	N	117
44	Y	53
45	Y	81
46	N	78
47	N	32
48	N	114
49	N	82
50	Y	30
51	N	64
52	N	41
53	Y	6
54	N	34
55	N	118
56	N	45
57	N	120
58	N	76
59	N	90
60	N	116
61	N	93
62	N	117
63	N	115
64	N	96
65	N	24
66	N	91
67	N	92
68	N	39
69	N	10
70	N	116
71	N	74
72	N	86
73	N	31
74	N	78
75	N	66
76	N	109

77	N	95
78	N	120
79	N	109
80	N	43
81	Y	89
82	N	17
83	N	87
84	N	112
85	N	36
86	N	118
87	N	120
88	N	11
89	N	33
90	N	3
91	N	111
92	N	48
93	N	8
94	N	56
95	N	14
96	N	116
97	N	112
98	Y	4
99	N	119
100	N	60
101	N	19
102	Y	95
103	N	50
104	N	35
105	N	34
106	N	12
107	N	75
108	N	73
109	N	69
110	N	118
111	N	117
112	N	114
113	N	14
114	N	15
115	N	41

116	N	61
117	Y	72
118	N	2
119	N	17
120	N	65
121	Y	21
122	N	47
123	N	5
124	N	113
125	N	24
126	N	55
127	N	112
128	N	51
129	N	94
130	N	77
131	N	46
132	N	24
133	N	120
134	N	112
135	N	39
136	N	80
137	Y	1
138	N	52
139	N	84
140	N	110
141	N	7
142	N	20
143	N	85
144	N	35
145	Y	83
146	N	13
147	Y	63
148	N	85
149	Y	89
150	Y	18
151	N	12
152	N	48
153	N	28
154	N	31

155	N	91
156	N	96
157	N	10
158	N	71
159	N	42
160	N	22
161	N	50
162	N	39
163	N	9
164	Y	26
165	N	111
166	N	88
167	N	58
168	N	23
169	N	113
170	Y	63
171	N	49
172	N	69
173	N	3
174	N	16
175	N	7
176	N	10
177	N	119
178	N	113
179	N	115
180	N	92

Table 5: Package assignment information

4.2.3 Vehicle Route Information

The table below gives the origin shipping centre and destination shipping centre for each vehicle. For the current operating conditions, no plane is being used for the middle mile logistics of Oops.

Vehicle Number	Origin Shipping Centre	Destination Shipping Centre
1	8	6
2	4	1
3	9	10
4	7	3
5	1	5
6	3	8
7	10	9
8	4	7
9	6	7
10	7	8
11	9	1
12	10	7
13	6	9
14	4	9
15	1	9
16	3	4
17	9	3
18	3	2
19	1	10
20	7	9
21	10	1
22	10	6
23	5	7
24	8	4
25	5	9
26	3	7
27	7	6
28	7	2
29	4	8
30	8	1
31	10	6
32	6	4
33	1	9
34	9	8
35	6	7
36	1	3
37	5	8

38	4	7
39	4	1
40	8	3
41	9	10
42	4	3
43	6	7
44	5	4
45	2	4
46	9	6
47	4	8
48	2	9
49	6	1
50	5	2
51	8	10
52	1	6
53	5	7
54	2	10
55	4	8
56	7	4
57	6	4
58	9	4
59	9	8
60	1	3
61	5	2
62	5	6
63	10	5
64	7	6
65	4	2
66	7	2
67	8	3
68	9	1
69	1	4
70	6	5
71	2	5
72	8	3
73	3	6
74	4	5
75	7	10
76	3	1

77	7	10
78	5	3
79	5	9
80	6	10
81	8	9
82	10	4
83	2	3
84	9	2
85	9	2
86	2	10
87	1	10
88	4	10
89	3	8
90	9	6
91	4	9
92	8	5
93	9	4
94	2	7
95	1	10
96	2	6
97	Not Assigned	Not Assigned
98	Not Assigned	Not Assigned
99	Not Assigned	Not Assigned
100	Not Assigned	Not Assigned
101	Not Assigned	Not Assigned
102	Not Assigned	Not Assigned
103	Not Assigned	Not Assigned
104	Not Assigned	Not Assigned
105	Not Assigned	Not Assigned
106	Not Assigned	Not Assigned
107	Not Assigned	Not Assigned
108	Not Assigned	Not Assigned
109	7	3
110	5	8
111	6	8
112	1	7
113	3	6
114	5	1
115	2	8

116	7	1
117	3	10
118	4	6
119	5	10
120	6	3

Table 6: Vehicle route information

4.2.4 Operator Relocation Information

This table gives the information regarding the number of operators relocated, base shipping centre from which they are relocated and also the destination shipping centre to which they are relocated.

```
ampl: display z;
z [*,*]
:    1   2   3   4   5   6   7   8   9   10    :=
1    0   0   0   1   0   0   0   0   0   0
2    0   0   0   0   0   0   0   0   0   0
3    0   0   0   0   0   0   0   0   0   0
4    0   0   0   0   0   0   0   0   0   0
5    0   0   0   0   0   0   0   0   0   0
6    0   0   0   2   0   0   0   0   0   0
7    0   0   0   0   0   0   0   0   0   0
8    0   0   0   0   0   0   0   0   0   0
9    0   0   0   0   0   0   0   0   0   0
10   0   0   0   0   0   0   4   0   0   0
;
```

Fig 10: Operator relocation information

Number of operators relocated	Base Shipping Centre	Relocated Shipping Centre
1	1	4
2	6	4
4	10	7

Table 7: Operator relocation information

4.2.5 Vehicle Allocation Information

The table below gives the information regarding how the vehicles should be allocated from the depot to shipping centres at the beginning of the day.

Origin Shipping Center	Vehicle Number Assigned	Number of Trucks Assigned	Number of planes assigned	Number of trains assigned
1	5, 15, 19, 33, 36, 52, 60, 69, 87, 95, 112	10	0	1

2	45, 48, 54, 71, 83, 86, 94, 96, 115	8	0	1
3	6, 16, 18, 26, 73, 76, 89, 113, 117	7	0	2
4	2, 8, 14, 29, 38, 39, 42, 47, 55, 65, 74, 88, 91, 118	13	0	1
5	23, 25, 37, 44, 50, 53, 61, 62, 78, 79, 110, 114, 119	10	0	3
6	9, 13, 32, 35, 43, 49, 57, 70, 80, 111, 120	9	0	2
7	4, 10, 20, 27, 28, 56, 64, 66, 75, 77, 109, 116	10	0	2
8	1, 24, 30, 40, 51, 67, 72, 81, 92	9	0	0
9	3, 11, 17, 34, 41, 46, 58, 59, 68, 84, 85, 90, 93	13	0	0
10	7, 12, 21, 22, 31, 63, 82	7	0	0

Table 8: Vehicle allocation from depot information

5.0 Solution Analysis

This section of the report gives the answers to the what if questions of the client and also explains the approach the firm took to answer these questions.

5.1 Maximum operating cost for a plane for which it is optimal to use at least one plane

The maximum operating cost for a plane for which it is optimal to use at least one plane is $46/mile. The total cost incurred in middle mile decreases to $38995 from $39008 and the number of tardy packages is decreased from 25 to 23. Including a plane has ensured package numbers 8 and 18 are delivered on time. The plane included is vehicle number 104 and is assigned to route starting from shipping centre 9 and ending at 6. The firm arrived at this maximum value for which it is optimal to use at least one plane by reducing the operating cost of plane by $1 for each iteration and by checking if any plane is assigned to any shipping centre. The iterations were stopped when at least one plane was being assigned.

```
Gurobi 9.5.2: optimal solution; objective 38995
1662628 simplex iterations
8037 branch-and-cut nodes
ampl: display T;
T [*] :=
  1 0    19 0    37 0    55 0    73 0    91 0   109 0   127 0   145 1   163 0
  2 0    20 1    38 0    56 0    74 0    92 0   110 0   128 0   146 0   164 1
  3 0    21 0    39 0    57 0    75 0    93 0   111 0   129 0   147 1   165 0
  4 0    22 0    40 1    58 0    76 0    94 0   112 0   130 0   148 0   166 0
  5 0    23 0    41 0    59 0    77 0    95 0   113 0   131 0   149 1   167 0
  6 0    24 0    42 1    60 0    78 0    96 0   114 0   132 0   150 1   168 0
  7 0    25 0    43 0    61 0    79 0    97 0   115 0   133 0   151 0   169 0
  8 0    26 0    44 1    62 0    80 0    98 1   116 0   134 0   152 0   170 1
  9 0    27 1    45 1    63 0    81 1    99 0   117 1   135 0   153 0   171 0
 10 1    28 0    46 0    64 0    82 0   100 0   118 0   136 0   154 0   172 0
 11 0    29 0    47 0    65 0    83 0   101 0   119 0   137 1   155 0   173 0
 12 0    30 1    48 0    66 0    84 0   102 1   120 0   138 0   156 0   174 0
 13 0    31 0    49 0    67 0    85 0   103 0   121 1   139 0   157 0   175 0
 14 0    32 0    50 1    68 0    86 0   104 0   122 0   140 0   158 0   176 0
 15 1    33 0    51 0    69 0    87 0   105 0   123 0   141 0   159 0   177 0
 16 0    34 0    52 0    70 0    88 0   106 0   124 0   142 0   160 0   178 0
 17 0    35 0    53 1    71 0    89 0   107 0   125 0   143 0   161 0   179 0
 18 0    36 0    54 0    72 0    90 0   108 0   126 0   144 0   162 0   180 0
;
```

Fig 11: AMPL output displaying number of tardy packages when operating cost for plane is made $46

97	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0
101	0	0	0	0	0	0	0	0	0	0
102	0	0	0	0	0	0	0	0	0	0
103	0	0	0	0	0	0	0	0	0	0
104	0	0	0	0	0	1	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0
106	0	0	0	0	0	0	0	0	0	0
107	0	0	0	0	0	0	0	0	0	0
108	0	0	0	0	0	0	0	0	0	0

Fig 12: AMPL output displaying assignment of a plane

5.2 Graph to choose the best trade-off between competing "goals" of cost vs Number of allowed late packages

This graph shows the trade-off between cost and maximum number of allowed tardy packages. To obtain the objective values for different number of tardy packages, a constraint $\sum_{p=1}^{P} T_{\mathrm{p}}$ = s where (s = 3..25).
We calculated the minimum value of number of packages being tardy to be 3 because if we set it to 0,1,2 the solution was coming out to be infeasible. Maximum value of package that can be tardy should be set as 25 (what we got from the objective function) because if we increase the package beyond this number both cost and number of packages being tardy will increase. So, considering this region of going beyond 25 tardy packages doesn't make sense from business point of the company as it is a lose-lose situation.
Below the value of 25 packages being tardy, there is trade-off going on between total cost incurred in middle mile logistics and number of packages being tardy. Depending on Oops goal of cost vs reputation, they can choose the number of tardy packages that they think will satisfy the company's objective. i.e., if the total cost is an important factor, the company should not worry about decreasing the tardy packages from the optimal value and if the reputation of company is an important factor, the management should choose a value on number of packages being tardy which they think will still be profitable to the company.

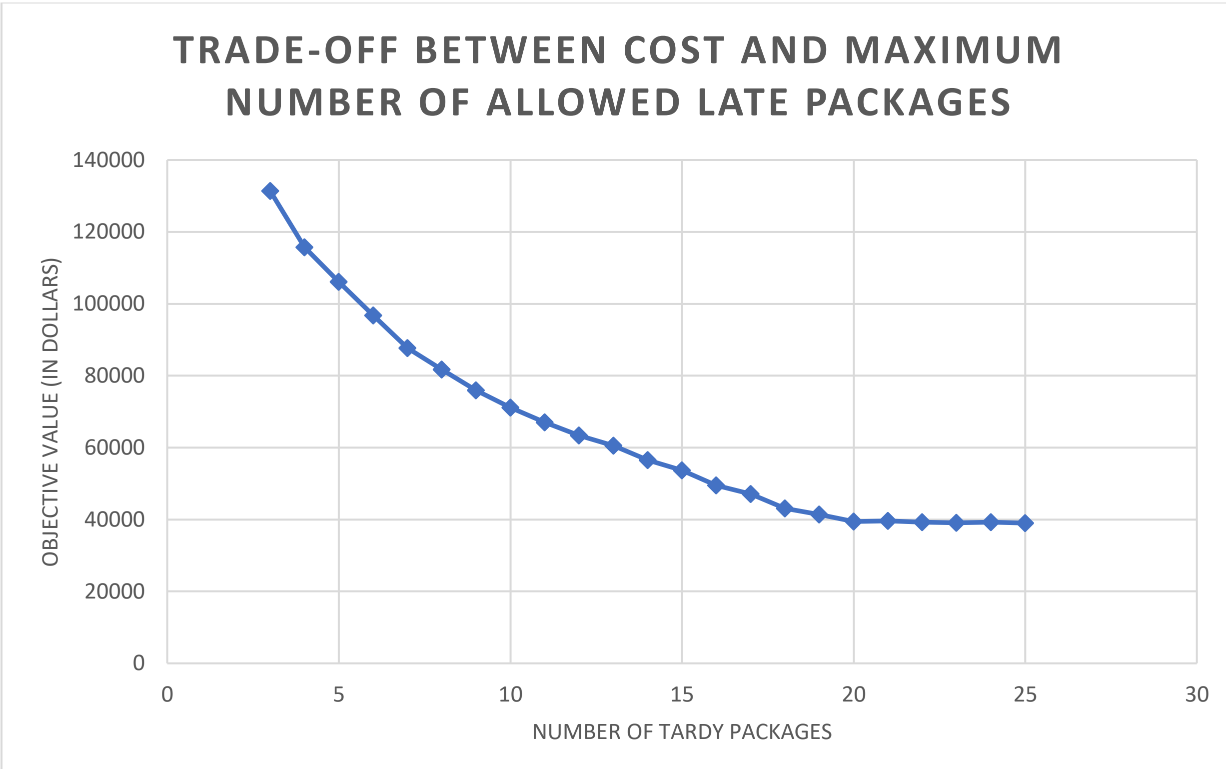

Fig 13: Trade off between cost and maximum number of allowed late packages

5.3 Solution analysis to determine the solution time

5.3.1 Time to solve Big-M less model

The time it took to solve the Big-M less model keeping all other applications closed is 171.937 seconds

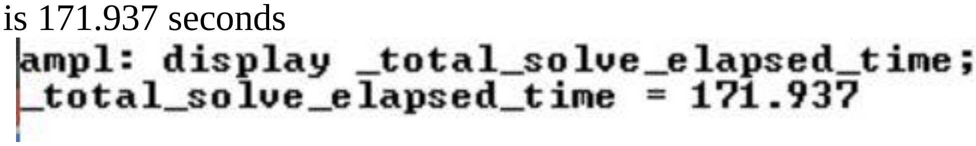

Fig 14: AMPL Output

5.3.2 Solution analysis for computing Big M values

In our optimization model, we have only 1 constraint in which we are using the concept of BIG-M which is constraint 4. So, to calculate theoretically smallest value of M it should be calculated such that, it is feasible for all situations that is for all packages. As in the constraint M only is included when t [v, s[p],e[p]] is greater than f[p]. So the largest value of t [v, s[p],e[p]]-f[p] is when we take the Maximum value of t[v,s[p],e[p]] which is basically the route with maximum distance and truck being assigned to that route (as it's the slowest vehicle) and value of transit time of the package p. BIG-M values calculated are given in table below.

$M[p] = Max(t[v,s[p],e[p]]) – Min(f[p])$

Package Id	M-value
1	88
2	61
3	75
4	70
5	75
6	89
7	64
8	70
9	87
10	88
11	80
12	65
13	79
14	63
15	82
16	68
17	67
18	89
19	76
20	74
21	84
22	73
23	74
24	75
25	69
26	87
27	85
28	77
29	78
30	70
31	89

32	57
33	55
34	64
35	85
36	65
37	59
38	70
39	65
40	92
41	84
42	74
43	89
44	82
45	80
46	61
47	86
48	66
49	73
50	70
51	56
52	61
53	61
54	61
55	67
56	73
57	67
58	86
59	75
60	73
61	86
62	66
63	92
64	81
65	71
66	78
67	68
68	55
69	88
70	67

71	63
72	89
73	62
74	78
75	75
76	81
77	60
78	88
79	85
80	63
81	81
82	78
83	62
84	77
85	84
86	59
87	56
88	62
89	64
90	67
91	61
92	73
93	92
94	94
95	84
96	75
97	80
98	59
99	64
100	86
101	58
102	89
103	93
104	76
105	59
106	89
107	68
108	64
109	58

110	57
111	77
112	59
113	68
114	56
115	73
116	61
117	75
118	83
119	56
120	88
121	68
122	63
123	61
124	88
125	77
126	68
127	85
128	60
129	84
130	87
131	87
132	56
133	84
134	63
135	88
136	80
137	86
138	82
139	85
140	76
141	69
142	59
143	78
144	64
145	84
146	79
147	87
148	62

149	74
150	70
151	58
152	92
153	73
154	58
155	90
156	58
157	80
158	75
159	84
160	61
161	72
162	57
163	82
164	63
165	76
166	88
167	90
168	58
169	92
170	62
171	91
172	56
173	67
174	64
175	59
176	55
177	94
178	71
179	75
180	62

Table 9: Big M values

5.3.3 Solution analysis to compute the solution time for smallest Big M values

Setting each Big-M to its smallest value for each package we solved the problem. The time taken to complete the solution was 145.562 seconds. Which is 28.375 seconds faster than the Big-M model reported previously.

```
Gurobi 9.5.2: optimal solution; objective 39008
2000734 simplex iterations
13329 branch-and-cut nodes
ampl: display _total_solve_elapsed_time;
_total_solve_elapsed_time = 145.562
```

Fig 15: AMPL Output

5.3.4 Solution analysis to determine Mega M

So based on the Big-M values calculated we find Mega-M values as the maximum value of all Big-M which comes out to be 94. The time taken to solve the model when all the Big-M values are set equal to Mega-M was 208.65 seconds. This model took 34.238 seconds more than that of BIG-M less model and 62.703 seconds more than that of BIG-M model (part b).

BIG-M less Model (part a)	**BIG-M model (part-b)**	**MEGA-M model (part c)**
173.937 seconds	145.562 seconds	208.265 seconds

```
Gurobi 9.5.2: optimal solution; objective 39008
1488389 simplex iterations
7628 branch-and-cut nodes
ampl: display _total_solve_elapsed_time;
_total_solve_elapsed_time = 208.265
```

Fig 16: AMPL Output

5.3.5 Solution analysis to plot a graph of Computational time v/s Big M values

For big m model we have to choose correct m factor (for optimum computation time) which varies based on different input thus when a new input data is entered, we have to recalculate optimum value of M and this issue can easily be avoidable in big-m less model

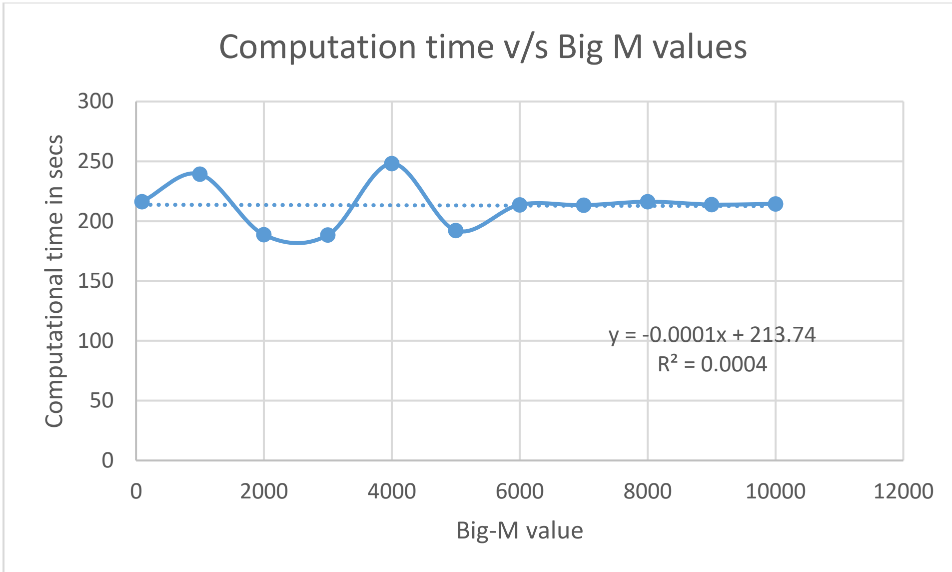

Fig 17: Computation time v/s Big M values

5.4 Additional Sensitivity Analysis

5.4.1 Sensitivity analysis by changing the data

Oops Management has been getting a lot of requests from labor union to reduce the maximum weight capacity of trucks in light of many accidents. The drivers are complaining about the lack of maneuverability of the trucks and there has been a sharp increase in number of trucks getting toppled over leading to driver death in the last few months. To respond to this serious scenario our firm planned on determining the minimum weight carrying capacity of trucks for which our solution is still feasible. To arrive at the minimum weight capacity, we decreased the maximum weight capacity of truck by 50kgs for every iteration and found out that the solution is still feasible when we reached 1000kg capacity. When we checked for 950 kg truck capacity, the solution became infeasible and to ensure the validity we started decreasing the maximum weight of truck by 1kg for every iteration and found out that the minimum weight capacity of truck for which solution is optimal is 995kg. The total cost increases to $61888 at this maximum weight capacity of truck. Thus, the maximum value by which we can decrease weight capacity of trucks is 205 kgs.

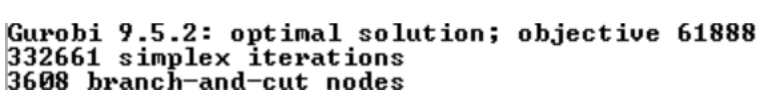

Fig 18: AMPL Output

5.4.2 Sensitivity analysis by modifying the model

The local government agencies are renovating the roads connecting shipping centres 8 and 10 and also the environmental activists are on a protest against the record increase in greenhouse gases this month and have blocked roads connecting shipping centres 1 and 9. Due to these situations, Oops cannot use trucks between shipping centres 1&9 and also between 8&10. To plan the middle mile logistics for such a situation, we have used four additional constraints in the model.

$$y_{v,1,9}=0 \qquad (v=1..96)$$
$$y_{v,9,1}=0 \qquad (v=1..96)$$
$$y_{v,8,10}=0 \qquad (v=1..96)$$
$$y_{v,10,8}=0 \qquad (v=1..96)$$

After solving the model again with new constraints, the total cost for middle mile logistics of Oops has increased to $42615. To ensure these constraints are working properly as intended, we verified if any truck is being assigned to these routes and found out that none of the 96 trucks were being assigned to these routes. The number of tardy packages has increased to 28 from 25.

```
Gurobi 9.5.2: optimal solution; objective 42615
1186582 simplex iterations
7110 branch-and-cut nodes
```

Fig 19: AMPL Output

5.4.3 Sensitivity analysis with graph

Oops supervisor contacted you about another problem. He explained that the currently being used trucks are very old and because of this along with operating costs we need to consider maintenance as well as service cost. Based on their experience, he suggested that the total operating cost + maintenance cost + service of the truck will change each year as per the table below. He wants to understand the impact of the additional cost of trains each year will have on the total cost. Based on this analysis, the management will plan to have new trains which will be very expensive but will have a smaller operating cost. So, considering this net 7-year change in the cost (assuming that all delivery and package info remains the same) the management will make a decision of investing in a new model of trains or continuing with the previous model only.

Year	Operating cost ($)	Total Cost ($)
1	10	39008
2	11	40468
3	13	43034
4	16	44619
5	20	50686
6	27	57002
7	35	64146

Table 9: Sensitivity Analysis

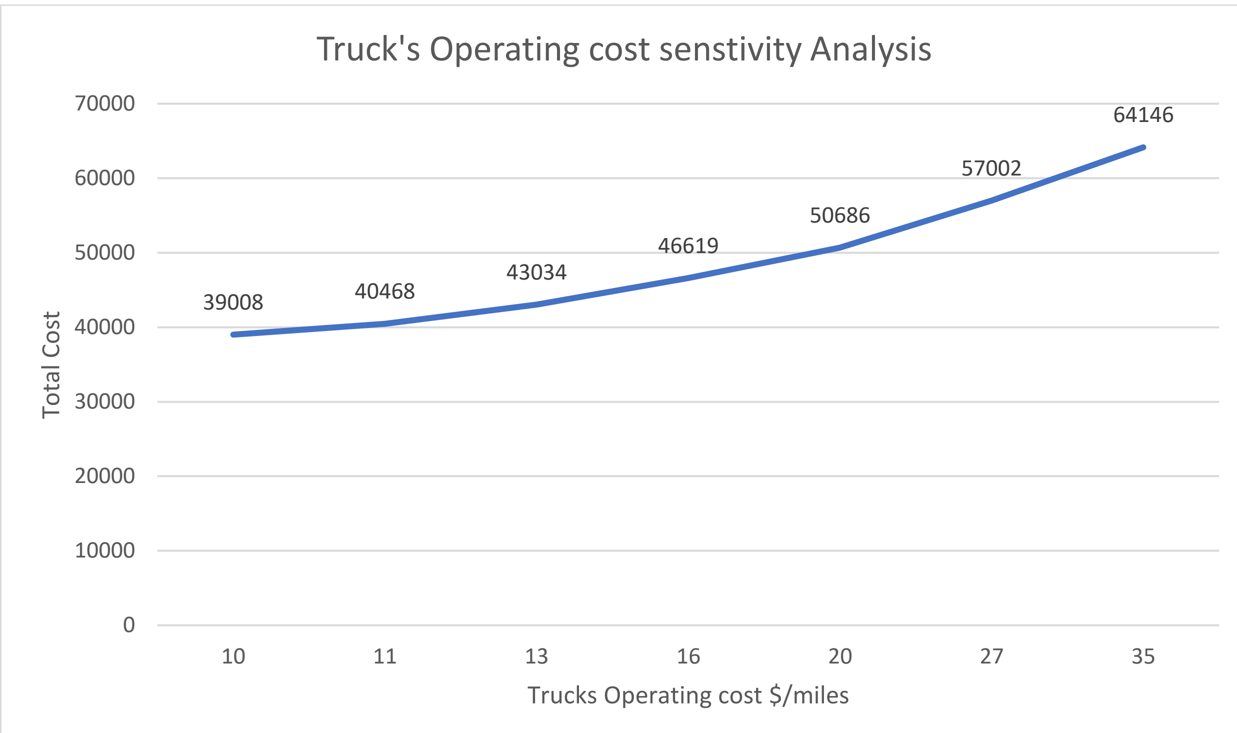

Fig 20 : Graph of sensitivity analysis

6.0 Conclusion

This report has detailed the creation of an Mixed Integer Linear Programming model, which was used to decide the best placement of Oops drivers and vehicles at shipping locations for the company's middle mile logistics. AMPL was used to find a solution that decreases Oops' overall cost to $39,008 while also meeting criteria including vehicle weight capacities, package incompatibilities, and loading and unloading constraints at shipping locations. 25 packages will be delivered late as a result of this method, which solely calls for the employment of trucks and trains. We recommend Oops to use our model to plan their middle mile logistics.

7.0 References

Cover image reference:

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