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Efficient Transportation Planning: A Case Study of Multi-Dimensional Solid Transportation Problem

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Abstract

This paper presents the application of a multi-dimensional solid transportation problem to optimize the distribution of a soft drink company's trucks in Egypt. The objective was to minimize the fuel consumption cost by taking into consideration the vehicle capacities in addition to the destinations and sources. The results of the study demonstrated a significant improvement of 22% compared to the company's current fleet distribution, leading to an annual saving of approximately 5 million pounds in fuel consumption. These findings highlight the efficacy of the proposed approach in solving large-scale transportation problems and improving operational costs.

Keywords: optimization, LINGO, solid transportation

1. Introduction

The transportation problem (TP) is a well-known type of Linear Programming Problem (LPP) that involves identifying the most cost-effective shipping routes and quantities for transferring a homogeneous commodity from multiple sources to multiple destinations. The solid transportation problem (STP) is a specific instance of the LPP, where constraints are placed on supply, demand, and transportation capacity. In several industrial scenarios, the transportation of a homogeneous product from its origin to its destination involves multiple modes of conveyance, such as trucks, trains, planes, and ships[1, 2].

The STP was initially formulated by Schell[3], and Haley [4] subsequently solved it using the modified distribution method of the classical transportation problem to obtain an optimal solution. Several formulations have been developed to find either near-optimal or optimal solutions for the STP[5, 6]

The multi-dimensional solid transportation problem (MDSTP) was later investigated in the presence of additional dimensions such as multi-stages in the transportation process or transportation of multiple products [7]

The multi-dimensional solid transportation problem (MDSTP) extends the classical transportation problem by incorporating additional layers of complexity, such as multiple product types, varied vehicle capacities, and multi-stage transportation processes[8, 9]. Unlike traditional transportation problems, which typically assume homogeneity in vehicles and products, MDSTP is designed to handle scenarios where these assumptions do not hold. This is particularly relevant for industries like logistics and supply chain management, where the need to optimize across various dimensions is crucial[10]. In the context of the soft drink company studied here, MDSTP allows for a nuanced optimization that considers not only the cost of transportation but also the specific capacities and constraints associated with different truck types and product varieties. By employing MDSTP, we aim to achieve a more precise and practical solution that aligns with the real-world operational complexities faced by the company[11].

Kakran et al. [12] presented a study on a multi-objective capacitated solid transportation problem in an uncertain environment with zigzag uncertain variables. Two models, expected value model and optimistic value model, are developed to deal with the uncertain MOCSTP model using two different ranking criteria of uncertainty theory. The results show that both methods provide a compromise solution, but the optimistic value model provides multiple solutions based on the confidence levels.

Aktar et al. [13] developed multi-objective transportation models for minimizing transportation cost, time, and carbon emissions, while considering incompatible and breakable/damageable multi-items and multiple paths. The study tests different methods to solve the formulated models and presents a real-life example to demonstrate the effects of green corridors and incompatibility among items on transportation cost, time, and carbon emissions. The TOPSIS method is used for ranking to identify the best suitable model among the formulated ones. The research suggests that waste time at toll plazas may be avoided with advanced payment systems.

This paper applies the MDSTP approach to optimize the distribution of the truck fleet for one of the largest soft drink companies in Egypt. The problem is formulated as an LPP, and the LINGO software (Linear Interactive and General Optimizer) is employed to solve it. The formulated problem considers crisp values for transportation cost, supply, demand, and fleet capacity.

2. Case Study

The present study focuses on the multi-objective multi-dimensional solid transportation problem at a water and soda water company located in Egypt[14, 15]. The company owns eight factories and distributes its products daily to 25

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distribution centers in various cities across the country, using a fleet of hundreds of trucks of different types and sizes. The objective of the study is to optimize the distribution of the transportation fleet by reducing fuel consumption and minimizing the time required for the trucks to transport products from sources to destinations.

The study aims to determine the number of trucks required to be present at each factory that will move daily to distribute the company's products. This will be achieved by redistributing the share of each source from the fleet to achieve an optimal solution without altering the quantity of factory production or the volume of orders for distribution centers.

The transportation problem under consideration would have been a classic transportation problem if all trucks were of the same type, size, and capacity and transported only one product. However, due to the heterogeneity of the trucks and the existence of three types of products, the transportation problem becomes a four-dimensional solid transportation problem.

The study collected data on the company's transport fleet and classified the trucks into three types based on their capacity. The transportation of three different types of products was examined, The movables are all of the same capacity, but the difference in type is due to the different taste and flavor, not the weight and size. The model was formulated based on this assumption.

3. Mathematical Formulation

The current study involves the modification of the mathematical model of the solid transportation problem to enable the solution of the problem under investigation. The primary objective of this modification is to create a framework that can solve the multi-dimensional solid transportation problem (MDSTP)[16].

The resulting mathematical model is formulated as follows:Let I, J, K, and P be the sets of factories, distribution centers, types of conveyances and product types respectively.

Let i ∈ I denote the ith factory, j ∈ J denote the jth center, k ∈ K denote the kth conveyance, and p ∈ P denote the pth product. i, j, k, and t are the indices (dimensions)[17, 18].

$$\text{Min } Z = \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} \sum_{p \in P} c_{ijk}\, x_{ijkp} \tag{1}$$

$$\sum_{j \in J} \sum_{k \in K} x_{ijkp} = a_{ip} \quad \text{for } \forall \;\; p=1:P; \quad i=1:I \tag{2}$$

$$\sum_{i \in I} \sum_{k \in K} x_{ijkp} = b_{jp} \quad \text{for } \forall \;\; p=1:P; \quad j=1:J \tag{3}$$

$$\sum_{i \in I} \sum_{j \in J} \sum_{p \in P} x_{ijkp} = e_k \quad \text{for } \forall \;\; k=1:K; \tag{4}$$

$$x_{ijkp} \geq 0 \; for \; \forall \; j, j, k, p \tag{5}$$

Where:

z = objective function
x_{ijkp}= the number of ballets that transported of type p from source i to destination j by conveyance k
c_{ijk} = unit transportation cost for shipped one ballet of any product from source i to destination j by conveyance k
a_i = number of ballets of each type of products available in source i
b_j = number of ballets of each type of products demand at destination j
e_k = the number of ballets that can carried by conveyance k

After calculating the number of products that are transported from each source to each destination by any of the existing truck types, we have formulated an equation to determine the size of the fleet of each type that moves daily from each garage to all destinations to ship various products as follows:

$$z_{ik} = \left(\sum_{j \in J} \sum_{p \in P} x_{ijkp} \right) / C_k \quad \text{for } \forall \;\; k=1:K; \quad i=1:I \tag{6}$$

where:
z_{ik} = number of trucks from type k moved daily from factory i
C_k = Total capacity of truck k

The program created by Lingo was utilized to formulate the above equation and show the results as decision variables[19].In this MDSTP model, constraints ensure logistical requirements are met across multiple dimensions: factories, distribution centers, vehicle types, and product types. Supply constraints ensure that shipments from each factory do not exceed available stock, while demand constraints ensure that each distribution center receives the required quantities. Vehicle capacity constraints prevent overloading by adhering to the specific capacities of each truck type: small trucks with a capacity of 150 pallets, medium trucks with 300 pallets, and large trucks with 500 pallets. For example, when distributing three different beverage types, the model simultaneously applies these constraints to determine the optimal allocation of trucks and products, balancing supply, demand, and transportation costs efficiently

4. Methodology

The methodology section of this paper presents a case study of a transportation fleet for a company with hundreds of trucks that settle daily in its garage close to the company's eight factories. The company's mission is to transport products daily to 25 distribution centers. The company's transport fleet comprises trucks of different capacities and sizes to suit the quantities required by the main destinations and its capabilities in storage and distribution. This diversity in truck capacities led to a balance between reducing transportation costs and time - and thus rapid fulfillment of product requirements - and ensuring the availability of trucks that fit quantities of any size without wasting truck capacities so that the truck does not carry a few percentages of its capacities.

We selected truck capacities of 150 pallets (small), 300 pallets (medium), and 500 pallets (large) based on the company's existing fleet composition and operational needs, ensuring a balance between maximizing load efficiency and minimizing transportation costs. These specific capacities were chosen to reflect the company's current logistical setup, where varied truck sizes accommodate different shipment volumes without incurring the inefficiencies associated with underutilized capacity. Data for the study was collected from company records, including truck capacities, fuel consumption rates, and daily production and distribution requirements. Distances between factories and distribution centers were manually calculated using Cairo Map and Google Maps due to the unavailability of direct distance data from the company

The distance matrix between each source and each distribution center was created, forming the basis for configuring the transportation network for fuel consumption costs. Due to the company's inability to provide direct distances between garages and distribution centers, these distances were manually calculated using Egypt Map and Google Maps. The measured distances, as shown in Table (1), are presented in kilometers (Km). To ensure the accuracy and reliability of the data, these distances were meticulously documented and cross-verified with the company's existing logistics data, reflecting the actual routes used in the company's operations. This robust approach provides a solid foundation for the optimization model, ensuring that the distances used are precise and representative of real-world conditions.

The daily production for each factory and the daily requirement for each distribution center of the three products were determined. Table (2) shows the total average daily production for each type of product, and Table (3) shows the total average daily consumption for each type of product.

To facilitate the study and work of the mathematical model to solve the problem, the trucks were classified into three types based on their capacity for pallets: Type A, with a small capacity of 150 pallets on average; Type B, with a medium capacity of 300 pallets on average; and Type C, with a large capacity of 500 pallets on average. The average fuel consumption for each type of truck has been calculated from company records, with consumption rates of 17, 25, and 30 l/100 km, respectively.

Accordingly, the cost of fuel consumption was calculated for each type of truck from each source to each destination. Table (4) shows the cost of fuel consumption per truck from each source to each destination. Depending on the capacity of each type of truck, we calculated the cost of fuel consumption in Egyptian pounds to transport one pallet from all factories to the distribution centers. Table 5 shows the cost of Fuel Consumption Per Pallet Across Different Routes and Truck Types. This table highlights the variability in fuel costs depending on truck capacity and route distance, providing insights into the cost-efficiency of various logistics strategies

According to the data available in the company, which shows the quantities of production and the need for various products and truck capacities, a solid transportation approach was proposed to solve the problem under study. The solid transportation problem can be formulated to solve the problem as shown in equations (1:5). After that, we determine the size of the fleet of each type that moves daily from each garage to all destinations to ship various products as shown in equation (6). The model was solved using the Lingo program, and the optimal distribution of trucks to reduce fuel consumption was compared to the company's current distribution, and the results were shown.

Table 1. The distances between each source and each destination in kilometers (Km).

Destination / Source	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	56	64	62	281	503	238	143	118	173	126	183	218	138	113	227	470	630	730	945	800	159	159	246	466	566
2	56	68	33	239	460	200	125	107	140	118	173	200	161	130	236	472	662	723	932	803	167	167	358	522	600
3	83	74	67	253	454	270	156	130	171	153	213	244	131	90	218	423	600	670	932	740	215	215	300	605	650
4	288	310	260	71	292	91	178	214	211	345	266	269	368	318	466	798	958	985	1285	1115	416	416	346	723	779
5	138	158	116	188	466	152	66	75	92	109	113	126	251	201	363	563	763	863	1070	887	237	221	250	590	629
6	184	231	177	237	512	166	118	148	148	91	54	54	296	243	391	614	816	872	1105	946	230	190	100	620	664
7	155	118	185	368	604	304	285	274	319	259	319	326	77	90	102	279	445	555	775	605	301	301	389	779	827
8	560	536	584	816	1081	765	678	627	667	632	661	681	529	541	461	408	388	432	560	425	584	595	672	490	960

Table 2. The total average daily production for each type of product

Source	P1	P2	P3
S1	5000	2000	3000
S2	2000	750	850
S3	3500	1300	2400
S4	6500	2000	3000
S5	5000	2750	2850
S6	1500	700	800
S7	3500	1500	1100
S8	8000	4000	6000
Total	35000	15000	20000
			70000

Table 3. The total average daily consumption for each type of product.

	P1	P2	P3		P1	P2	P3
D1	6800	1200	2500	**D14**	250	250	100
D2	1200	2600	1700	**D15**	1700	200	900
D3	2600	1200	1100	**D16**	1200	900	200
D4	4900	1100	2000	**D17**	1700	300	1000
D5	500	100	200	**D18**	700	400	400
D6	1000	850	400	**D19**	650	250	400
D7	3000	600	1200	**D20**	500	150	150
D8	900	200	400	**D21**	1050	800	650
D9	400	300	200	**D22**	900	450	850

D10	1100	700	1400	**D23**	700	600	700
D11	800	250	400	**D24**	450	300	750
D12	950	150	900	**D25**	100	400	700
D13	950	750	800	**Total**	35000	15000	20000
							70000

Table 4. The cost of fuel consumption per truck from each source to each destination

	D1			D2			D3			D4			D5		
	k1	k2	k3	k1	k2	k1	k2	k3	k1	k2	k1	k2	k3	k1	k2
S1	69	102	122	79	116	139	76	112	135	346	509	611	620	912	1094
S2	69	102	122	84	123	148	41	60	72	295	433	520	567	834	1001
S3	102	150	181	91	134	161	83	121	146	312	459	550	560	823	987
S4	355	522	626	382	562	674	320	471	566	88	129	154	360	529	635
S5	170	250	300	195	286	344	143	210	252	232	341	409	574	845	1014
S6	227	334	400	285	419	502	218	321	385	292	430	515	631	928	1114
S7	191	281	337	145	214	257	228	335	402	454	667	800	744	1095	1314
S8	690	1015	1218	661	972	1166	720	1059	1270	1006	1479	1775	1332	1959	2351
	D6			D7			D8			D9			D10		
	k1	k2	k3	k1	k2	k1	k2	k3	k1	k2	k1	k2	k3	k1	k2
S1	293	431	518	176	259	311	145	214	257	213	314	376	155	228	274
S2	247	363	435	154	227	272	132	194	233	173	254	305	145	214	257
S3	333	489	587	192	283	339	160	236	283	211	310	372	189	277	333
S4	112	165	198	219	323	387	264	388	465	260	382	459	425	625	750
S5	187	276	331	81	120	144	92	136	163	113	167	200	134	198	237
S6	205	301	361	145	214	257	182	268	322	182	268	322	112	165	198
S7	375	551	661	351	517	620	338	497	596	393	578	694	319	469	563
S8	943	1387	1664	836	1229	1475	773	1136	1364	822	1209	1451	779	1146	1375
	D11			D12			D13			D14			D15		
	k1	k2	k3	k1	k2	k1	k2	k3	k1	k2	k1	k2	k3	k1	k2
S1	226	332	398	269	395	474	170	250	300	139	205	246	280	411	494
S2	213	314	376	247	363	435	198	292	350	160	236	283	291	428	513
S3	263	386	463	301	442	531	161	237	285	111	163	196	269	395	474
S4	328	482	579	332	488	585	454	667	800	392	576	692	574	845	1014
S5	139	205	246	155	228	274	309	455	546	248	364	437	447	658	790
S6	67	98	117	67	98	117	365	537	644	299	440	529	482	709	850
S7	393	578	694	402	591	709	95	140	167	111	163	196	126	185	222
S8	815	1198	1438	839	1234	1481	652	959	1151	667	981	1177	568	836	1003
	D16			D17			D18			D19			D20		
	k1	k2	k3	k1	k2	k1	k2	k3	k1	k2	k1	k2	k3	k1	k2
S1	579	852	1022	776	1142	1370	900	1323	1588	1165	1713	2055	986	1450	1740
S2	582	856	1027	816	1200	1440	891	1310	1573	1149	1689	2027	990	1455	1747
S3	521	767	920	740	1088	1305	826	1214	1457	1149	1689	2027	912	1341	1610
S4	984	1446	1736	1181	1736	2084	1214	1785	2142	1584	2329	2795	1374	2021	2425
S5	694	1020	1225	940	1383	1660	1064	1564	1877	1319	1939	2327	1093	1608	1929
S6	757	1113	1335	1006	1479	1775	1075	1581	1897	1362	2003	2403	1166	1715	2058
S7	344	506	607	548	807	968	684	1006	1207	955	1405	1686	746	1097	1316
S8	503	740	887	478	703	844	532	783	940	690	1015	1218	524	770	924
	D21			D22			D23			D24			D25		
	k1	k2	k3	k1	k2	k1	k2	k3	k1	k2	k1	k2	k3	k1	k2
S1	196	288	346	196	288	346	303	446	535	574	845	1014	698	1026	1231
S2	206	303	363	206	303	363	441	649	779	643	946	1135	740	1088	1305
S3	265	390	468	265	390	468	370	544	653	746	1097	1316	801	1178	1414
S4	513	754	905	513	754	905	426	627	753	891	1310	1573	960	1412	1694
S5	292	430	515	272	401	481	308	453	544	727	1069	1283	775	1140	1368
S6	283	417	500	234	344	413	123	181	218	764	1124	1349	818	1204	1444
S7	371	546	655	371	546	655	479	705	846	960	1412	1694	1019	1499	1799
S8	720	1059	1270	733	1078	1294	828	1218	1462	604	888	1066	1183	1740	2088

Table 5. The cost of fuel consumption per pallet.

	k1	**k2**	**k3**	**k1**	**k2**	**k3**	**k1**	**k2**	**k3**	**k1**	**k2**	**k3**	**k1**	**k2**	**k3**
S1	0.46	0.34	0.24	0.53	0.39	0.28	0.51	0.37	0.27	2.31	1.7	1.22	4.13	3.04	2.19
S2	0.46	0.34	0.24	0.56	0.41	0.3	0.27	0.2	0.14	1.97	1.44	1.04	3.78	2.78	2
S3	0.68	0.5	0.36	0.61	0.45	0.32	0.55	0.4	0.29	2.08	1.53	1.1	3.73	2.74	1.97
S4	2.37	1.74	1.25	2.55	1.87	1.35	2.13	1.57	1.13	0.59	0.43	0.31	2.4	1.76	1.27
S5	1.13	0.83	0.6	1.3	0.95	0.69	0.95	0.7	0.5	1.55	1.14	0.82	3.83	2.82	2.03
S6	1.51	1.11	0.8	1.9	1.4	1	1.45	1.07	0.77	1.95	1.43	1.03	4.21	3.09	2.23
S7	1.27	0.94	0.67	0.97	0.71	0.51	1.52	1.12	0.8	3.03	2.22	1.6	4.96	3.65	2.63
S8	4.6	3.38	2.44	4.41	3.24	2.33	4.8	3.53	2.54	6.71	4.93	3.55	8.88	6.53	4.7
	D6			D7			D8			D9			D10		
	k1	k2	k3	k1	k2	k3	k1	k2	k3	k1	k2	k3	k1	k2	k3
S1	1.95	1.44	1.04	1.17	0.86	0.62	0.97	0.71	0.51	1.42	1.05	0.75	1.03	0.76	0.55
S2	1.65	1.21	0.87	1.03	0.76	0.54	0.88	0.65	0.47	1.15	0.85	0.61	0.97	0.71	0.51
S3	2.22	1.63	1.17	1.28	0.94	0.68	1.07	0.79	0.57	1.41	1.03	0.74	1.26	0.92	0.67

S4	0.75	0.55	0.4	1.46	1.08	0.77	1.76	1.29	0.93	1.73	1.27	0.92	2.83	2.08	1.5
S5	1.25	0.92	0.66	0.54	0.4	0.29	0.61	0.45	0.33	0.75	0.56	0.4	0.89	0.66	0.47
S6	1.37	1	0.72	0.97	0.71	0.51	1.21	0.89	0.64	1.21	0.89	0.64	0.75	0.55	0.4
S7	2.5	1.84	1.32	2.34	1.72	1.24	2.25	1.66	1.19	2.62	1.93	1.39	2.13	1.56	1.13
S8	6.29	4.62	3.33	5.57	4.1	2.95	5.15	3.79	2.73	5.48	4.03	2.9	5.19	3.82	2.75
	D11			D12			D13			D14			D15		
	k1	k2	k3	k1	k2	k3	k1	k2	k3	k1	k2	k3	k1	k2	k3
S1	1.51	1.11	0.8	1.79	1.32	0.95	1.13	0.83	0.6	0.93	0.68	0.49	1.87	1.37	0.99
S2	1.42	1.05	0.75	1.65	1.21	0.87	1.32	0.97	0.7	1.07	0.79	0.57	1.94	1.43	1.03
S3	1.75	1.29	0.93	2.01	1.47	1.06	1.07	0.79	0.57	0.74	0.54	0.39	1.79	1.32	0.95
S4	2.19	1.61	1.16	2.21	1.63	1.17	3.03	2.22	1.6	2.61	1.92	1.38	3.83	2.82	2.03
S5	0.93	0.68	0.49	1.03	0.76	0.55	2.06	1.52	1.09	1.65	1.21	0.87	2.98	2.19	1.58
S6	0.45	0.33	0.23	0.45	0.33	0.23	2.43	1.79	1.29	1.99	1.47	1.06	3.21	2.36	1.7
S7	2.62	1.93	1.39	2.68	1.97	1.42	0.63	0.47	0.33	0.74	0.54	0.39	0.84	0.62	0.44
S8	5.43	3.99	2.88	5.59	4.11	2.96	4.35	3.2	2.3	4.45	3.27	2.35	3.79	2.79	2.01
	D16			D17			D18			D19			D20		
	k1	k2	k3	k1	k2	k3	k1	k2	k3	k1	k2	k3	k1	k2	k3
S1	3.86	2.84	2.04	5.17	3.81	2.74	6	4.41	3.18	7.77	5.71	4.11	6.57	4.83	3.48
S2	3.88	2.85	2.05	5.44	4	2.88	5.94	4.37	3.15	7.66	5.63	4.05	6.6	4.85	3.49
S3	3.47	2.56	1.84	4.93	3.63	2.61	5.51	4.05	2.91	7.66	5.63	4.05	6.08	4.47	3.22
S4	6.56	4.82	3.47	7.87	5.79	4.17	8.09	5.95	4.28	10.56	7.76	5.59	9.16	6.74	4.85
S5	4.63	3.4	2.45	6.27	4.61	3.32	7.09	5.21	3.75	8.79	6.46	4.65	7.29	5.36	3.86
S6	5.05	3.71	2.67	6.71	4.93	3.55	7.17	5.27	3.79	9.08	6.68	4.81	7.77	5.72	4.12
S7	2.29	1.69	1.21	3.65	2.69	1.94	4.56	3.35	2.41	6.37	4.68	3.37	4.97	3.66	2.63
S8	3.35	2.47	1.77	3.19	2.34	1.69	3.55	2.61	1.88	4.6	3.38	2.44	3.49	2.57	1.85
	D21			D22			D23			D24			D25		
	k1	k2	k3	k1	k2	k3	k1	k2	k3	k1	k2	k3	k1	k2	k3
S1	1.31	0.96	0.69	1.31	0.96	0.69	2.02	1.49	1.07	3.83	2.82	2.03	4.65	3.42	2.46
S2	1.37	1.01	0.73	1.37	1.01	0.73	2.94	2.16	1.56	4.29	3.15	2.27	4.93	3.63	2.61
S3	1.77	1.3	0.94	1.77	1.3	0.94	2.47	1.81	1.31	4.97	3.66	2.63	5.34	3.93	2.83
S4	3.42	2.51	1.81	3.42	2.51	1.81	2.84	2.09	1.51	5.94	4.37	3.15	6.4	4.71	3.39
S5	1.95	1.43	1.03	1.81	1.34	0.96	2.05	1.51	1.09	4.85	3.56	2.57	5.17	3.8	2.74
S6	1.89	1.39	1	1.56	1.15	0.83	0.82	0.6	0.44	5.09	3.75	2.7	5.45	4.01	2.89
S7	2.47	1.82	1.31	2.47	1.82	1.31	3.19	2.35	1.69	6.4	4.71	3.39	6.79	5	3.6
S8	4.8	3.53	2.54	4.89	3.59	2.59	5.52	4.06	2.92	4.03	2.96	2.13	7.89	5.8	4.18

Table (6) shows the basic variables (non-zero values of x_{ijkp}). Figure (1) describes the Lingo output. Table (7) shows the number of trucks from each type that should be present in each factory to distribute the products to the different destinations. Figure (2) shows the number of trucks of each type that move daily from each garage to all destinations loaded with various products.

Due to the incongruity between production, demand, and truck capacity, decimal values are observed in the results. It is not practical to bear the costs of transporting a truck that carries a small percentage of its capacity. Hence, it is possible to coordinate transportation to maintain a constant average transportation cost. For instance, 66.67 trucks move from the first factory to different destinations daily. Therefore, on the first and second days, 67 full-capacity trucks can be dispatched to the destinations, and on the third day, 66 trucks can be dispatched. The remaining shipments from the first two days, which were present in the distribution centers as stock, can complete the shortfall in what was shipped on the third day.

5. Results and Discussions

The proposed solid transportation approach was successfully applied to a company with a transportation fleet consisting of hundreds of trucks, settling daily in its garage near its eight factories, to transport products to 25 distribution centers. By formulating the problem and classifying trucks into three types based on their capacities, the cost of fuel consumption for each type of truck was calculated, and a mathematical model was developed to determine the optimal distribution of trucks to reduce fuel consumption.

Table 6. The basic variables (non-zero values of x_{ijkp}).

Var.	No. of ballet	Var.	No. of ballet	Var.	No. of ballet	Var.	No. of ballet	Var.	No. of ballet
X10111	5000	X40531	500	X51022	700	X71421	250	X82031	500
X10112	1200	X40532	100	X51023	450	X71422	250	X82032	150
X10113	2500	X40533	200	X51121	750	X71423	100	X82033	150
X10212	800	X40621	1000	X51122	250	X71521	1150	X82131	1050
X11023	500	X40622	800	X51123	400	X71523	200	X82132	800
X20311	2000	X40623	400	X51222	50	X81531	550	X82133	650
X20312	750	X40733	200	X51223	600	X81532	200	X82231	900
X20313	850	X40931	100	X52232	150	X81533	700	X82232	300
X30121	1800	X40933	200	X61111	50	X81631	1200	X82233	850
X30211	50	X50322	450	X61211	950	X81632	900	X82331	200
X30212	1300	X50632	50	X61212	100	X81633	200	X82333	200
X30213	1700	X50711	3000	X61213	300	X81731	1700	X82431	450

X30311	600	X50712	600	X62321	500	X81732	300	X82432	300
X30313	250	X50713	1000	X62322	600	X81733	1000	X82433	750
X31021	1000	X50811	900	X62323	500	X81831	700	X82531	100
X31031	50	X50812	200	X70221	1150	X81832	400	X82532	400
X31033	450	X50813	400	X70222	500	X81833	400	X82533	700
X40411	4900	X50921	300	X71311	950	X81931	650		
X40412	1100	X50922	300	X71312	750	X81932	250		
X40413	2000	X51021	50	X71313	800	X81933	400		

The Lingo program was used to solve the model, and the optimal solution was found to be 70165.50 LE. Comparing this cost with the current daily cost of fuel consumption, which is about 90000 LE, revealed an improvement rate of 22%. This improvement rate provides the company with an annual benefit of approximately 5 million Egyptian Pounds, based on the 250 actual working days during the year.

Therefore, the proposed transportation approach offers an efficient and effective solution to optimize truck distribution and reduce fuel consumption for companies with a similar transportation setup. The results of this study can provide valuable insights to transportation managers seeking to improve the efficiency of their fleet and reduce transportation costs.This research is notable for its capacity to identify the optimal deployment of a company's fleet that aligns with a predetermined objective, as well as its capability to resolve the challenge of solid transportation from a four-dimensional perspective, while taking into account the constraints associated with each dimension. The optimized transportation system achieved a 22% reduction in fuel consumption, contributing to the company's sustainability goals by supporting efficient resource utilization. This not only improves operational efficiency but also aligns with industry trends towards sustainable logistics practices, demonstrating the broader environmental and operational benefits of adopting MDSTP in transportation planning.

While the MDSTP model has demonstrated effectiveness in optimizing transportation logistics, certain limitations should be considered. The model's results are sensitive to changes in external factors such as fuel prices and fluctuations in demand, which could impact the accuracy of cost predictions and fleet allocation strategies. Additionally, the model assumes consistent operational conditions, and any significant deviations in these variables may require recalibration of the parameters or adjustment of the model to maintain its effectiveness. Acknowledging these limitations provides a more balanced perspective on the applicability of the MDSTP approach, emphasizing the need for ongoing evaluation and adaptation in dynamic real-world settings

Table 7. The number of trucks from each type that should be present in each factory to distribute the products to the different destinations

Var.	No. of trucks	Var.	No. of trucks
Z11	63.33	Z51	40.67
Z12	1.67	Z52	14.33
Z13	-	Z53	0.40
Z21	24	Z61	9.33
Z22	-	Z62	5.33
Z23	-	Z63	-
Z31	26	Z71	16.67
Z32	9.33	Z72	12.00
Z33	1	Z73	-
Z41	53.33	Z81	-
Z42	7.33	Z82	-
Z43	2.6	Z83	36.00

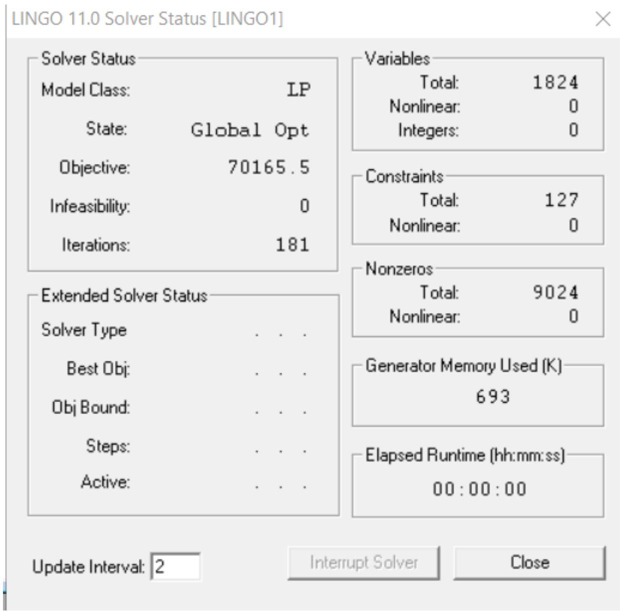

Fig. 1. The Lingo output

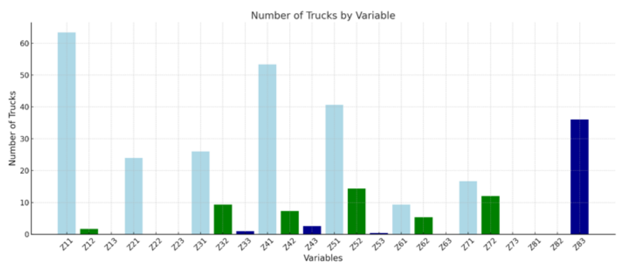

Fig. 2. The number of trucks of each type that move daily from each garage to all destinations loaded with various products

6. Conclusion

In conclusion, this paper addressed the multi-dimensional solid transportation problem of a major private sector company in Egypt. The objective was to determine the optimal distribution strategy for transporting various products from the company's factories to distribution centers and then to hypermarkets and markets. The study formulated and solved the problem using the Lingo solver[20, 21], with a customized mathematical approach to suit the requirements of the problem. The results demonstrated a 22% reduction in fuel consumption costs compared to the current transportation system. Overall, this study provides insights into the effective management of solid transportation problems and offers valuable implications for companies operating in similar industries. This study demonstrates the practical application of MDSTP in optimizing transportation logistics for a soft drink company, highlighting the approach's potential adaptability to other industries with similar multi-dimensional challenges in supply chain management. While focused on a specific context, the model's framework can be generalized for broader applications across various logistics and supply chain scenarios, providing a flexible and scalable solution to complex transportation problems encountered in diverse industries. This adaptability makes the MDSTP approach particularly valuable for optimizing distribution networks, managing inventory flows, and enhancing overall supply chain efficiency.

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