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***Abstract*—This document is a model and instructions for LaTeX. This and the IEEEtran.cls file define the components of your paper [title, text, heads, etc.]. *CRITICAL: Do Not Use Symbols, Special Characters, Footnotes, or Math in Paper Title or Abstract.**

***Index Terms*—component, formatting, style, styling, insert.**

I. Introduction

Cold storage has diverse applications over various industries. Fresh produce is kept in supermarkets on refrigeration racks to prevent thermal and bacterial spoilage, while raw products such as sashimi rely on cold storage to treat parasites in aquatic produce. In the medical industry, vaccines are stored under low temperatures to maintain antigen viability. The Pfizer-BioNTech vaccine requires a storage temperature of -80 °C due to thermal instability of mRNA and its encapsulating lipid nanoparticles as an example [1]. A large proportion of the products from these categorical examples are volatile under temperature changes, hence it is necessary to maintain temperature control throughout the product to consumer distribution chain. Cold storage during transport is often more costly than stationary storage due to lower energy efficiency, caused by variable ambient temperature and lower insulation [2], thus motivating a separate analysis of higher refrigeration costs in transport operations.

Additionally, cold chain transport produces greenhouse gases in the form of CO_2 and refrigerants in cases of leaks. Greenhouse gases are the primary cause of global warming and its subsequent effects of climate change, which includes but are not limited to an increased transmissibility of tropical diseases [3] and crop failure due to floods [4]. In accordance to decision making associated with corporate social responsibility and the UN SDG 13 (Climate Action), it is important to reduce the effects of cold chain transport to the climate and external stakeholders, motivating the analysis of variables affecting transport emissions.

We thus propose a model which aims to optimize transport costs, emissions, and customer satisfaction from a cold chain consisting of transport from suppliers to customers by employing Mixed Integer Linear Programming with Coin Branch and Cut and LSGA-2. The cold chain model is integrated with a customer satisfaction variable in order to reflect the importance of timeliness in transport to customers.

II. Literature Review

The optimization of cold-chain logistics networks has become critical in balancing cost, carbon emissions, and level of service. Liu et al. (2021) develop an integer-programming model for ”origin–DC–customer” routing of perishable products, with explicit energy-conservation and emission-reduction goals alongside inventory, damage, penalty, and refrigeration costs [5]. They compare a pure genetic algorithm with a hybrid GA–local-search on real-world data, demonstrating the hybrid approach yields more Pareto-front solutions for total cost and emissions.

For strategic facility location, Li and Zhou (2021) introduce a multi-objective mixed-integer programming model for cold-chain distribution center location that integrates dynamic transportation emissions, static DC emissions, construction and operational costs, and time-window penalty costs for customer satisfaction [6]. They employ NSGA-II, which employs fast non-dominated sorting and elitist selection, to derive Pareto-optimal trade-offs between cost, emissions, and service level.

Deb et al. (2002) suggested NSGA-II—a de facto standard for complicated, non-convex multi-criteria problems—which Li and Zhou apply to search extensive solution spaces under conflicting objectives [5]. Complementing this, Ehrgott (2005) discusses multi-criteria optimization methods, providing theoretical foundations for Pareto-frontier interpretation and supporting decision-maker preference elicitation in supply-chain applications [6].

Carbon-emission accounting in logistics has evolved from static factor models to more complex, load-dependent formulations. Min and Zhou (2002) encapsulate per-km emission factors and load ratios in location-allocation decisions, an approach similar in Liu et al.'s refrigerated-vehicle emission terms and Li and Zhou's dynamic-static emission splits [7]. Macharis et al. (2009) also distinguish between fixed DC emissions and transport emissions, corroborating the discrete θS_i and χ-terms in our model's carbon objective [8].

Time-window constraints and service-level penalties are a classic in vehicle routing. Solomon (1987) formalizes VRPTW with soft and hard time windows and early/late penalties analogous to our piecewise cost function $C(T_{jk})$ [9]. Savelsbergh and Sol (1995) review exact and heuristic VRPTW methods, offering practical insights on penalty-including routing heuristics that both Liu et al.'s and Li and Zhou's solution algorithms build on [10].

III. Problem Formulation

In our problem formulation, we have a set of I supplier, J distribution centers (DCs), and K customers, which can be thought of as supermarkets or stores. We act as both the suppliers and distributors of a product, starting without any distribution centers initially. The goal is to transport the goods while optimizing for the costs, carbon emissions, and customer utilitiy. As we have multiple objective functions, we often have to optimize for the best compromise [11], as an optimal solution for all might not exist.

There are costs associated with acting as bost supplier and distributor. First, the distribution centers must be built, if they haven't already. This has a cost associated per unit of area. Note that we can include the cost of buying the land into this if required, and we note we can set the costs as 0 if we already own the distribution centers. Next, there is also a cost associated with running the distribution facilities. This is proportional to the size of the facility. Although costs might vary per distribution center, we assume for simplicity that the costs are flat per unit of area. Finally, we also assume for simplicity we have infinite trucks to transport the goods.

There is also a cost associated with transporting te goods from the supply center to the distribution center, then from the distribution center to the customer. This is proportional to the number of trucks required, the distance between the locations, and the cost of transporting per km.

Finally, goods can be damaged in transport. We represent this as opportunity cost, as we can't sell damaged goods. The cost is proportional to the price of the object, the damage rate per km, as different objects could have different rates, and the distance traveled.

For carbon costs, it is proportional to the carbon efficiency of the vehicle (measured for example as carbon emissions / km), how far we must travel, and how full the truck, as more weight could result in more emissions [12]. Note we assume that all the trucks must return to their original individual supply centers, and so in one way there is the cost associated with the weight, but in the other the truck is empty.

Customer satisfaction is proportional to the arrival of the vehicles to the customer. If they are within a reasonable tolerance, it incurs no penalty. But if the vehicle arrives too late or too early, we incur a penalty proportional to how late or early we are.

Sets

- I : Set of suppliers
- J : Set of distribution centers (DCs)
- K : Set of customers

Parameters

- d_{ij} : Distance from supplier i to DC j
- d_{jk} : Distance from DC j to customer k
- N_k : Demand of customer k
- s_j : Area required for DC j
- z : Construction cost per unit area
- w facility cost per unit area
- e : Unit value of goods
- u : Damage rate per km
- δ : Transport cost per truck per km
- $\rho_{\max}, \rho_0$: Fuel consumption per km (full/empty)
- χ : Carbon cost of vehicle per km
- θ : Static carbon cost coefficient
- ϕ : CO_2 conversion per unit goods
- Q : Maximum vehicle load
- α_1, α_2 : Penalty coefficients for early/late delivery
- RT_k, LT_k : Time window boundaries for customer k
- U : Maximum penalty cost
- $\eta_j^{\max}$: Maximum number of vehicles allowed at DC j
- S_i: Maximum storage for DC i

Decision Variables

- $c_j \in \{0,1\}$: 1 if distribution center j is opened
- $x_{ij} \in \{0,1\}$: 1 if supplier i supplies DC j
- $y_{jk} \in \{0,1\}$: 1 if DC j serves customer k
- $t_{ij} \geq 0$: Quantity of goods transported from supplier i to DC j
- $t_{jk} \geq 0$: Quantity of goods transported from DC j to customer k
- $T_{jk} \geq 0$: Arrival time at customer k from DC j
- $\eta_j \in \mathbb{Z}_+$: Number of vehicles allocated to DC j

Objective Functions

1. Costs (C_c)

$$\begin{aligned}\min C_c = &\sum_{j\in J} c_j(zs_j + ws_j) \\ &+ \delta \sum_{i\in I}\sum_{j\in J} x_{ij}\lceil \frac{t_{ij}}{Q}\rceil d_{ij} + \delta \sum_{j\in J}\sum_{k\in K} y_{jk}\lceil \frac{t_{jk}}{Q}\rceil d_{jk} \\ &+ e\sum_{i\in I}\sum_{j\in J} x_{ij}ud_{ij} + e\sum_{j\in J}\sum_{k\in K} y_{jk}ud_{jk}\end{aligned} \tag{1}$$

2. Carbon Emission Cost (T_c)

$$\begin{aligned}\min T_c =& \theta S_i + \sum_{j\in J} c_j \phi \sum_{i\in I} t_{ij} \\ &+ \chi \sum_{i\in I}\sum_{j\in J} x_{ij}\left(\frac{\rho_{\max}-\rho_0}{Q} t_{ij} d_{ij} + \rho_0 d_{ij}\right) \\ &+ \chi \sum_{j\in J}\sum_{k\in K} y_{jk}\left(\frac{\rho_{\max}-\rho_0}{Q} t_{jk} d_{jk} + \rho_0 d_{jk}\right)\end{aligned} \tag{2}$$

3. Customer Satisfaction Penalty Cost (U_c)

$$\min U_c = \sum_{j\in J}\sum_{k\in K} y_{jk} \cdot C(T_{jk})$$

Where:

$$C(T_{jk}) = \begin{cases} \alpha_1(RT_k - T_{jk}), & T_{jk} < RT_k \\ 0, & RT_k \le T_{jk} \le LT_k \\ \alpha_2(T_{jk} - LT_k), & LT_k < T_{jk} \end{cases}$$

Constraints

$$t_{ij}, t_{jk} \ge 0 \quad \forall i,j,k \tag{3}$$

$$\sum_{i\in I} t_{ij} = \sum_{k\in K} t_{jk} \quad \forall j \tag{4}$$

$$\sum_{j\in J} c_j \ge 1 \tag{5}$$

$$\sum_{k\in K} t_{jk} \le \eta_j \cdot Q \quad \forall j \tag{6}$$

$$\sum_{j\in J} t_{jk} = N_k \quad \forall k \tag{7}$$

$$c_j, x_{ij}, y_{jk} \in \{0,1\} \quad \forall i,j,k \tag{8}$$

$$0 \le \eta_j \le \eta_j^{\max} \quad \forall j \tag{9}$$

IV. Variable Choices

Variables chosen are based on quantitative data done by the research of ???. Numerical values of the variables are given as following:

Variable	Description	Value	Source
$\rho_{\max}$	Fuel consumption under maximum weight	2.0610 l/km	[12]
ρ_0	Fuel consumption under zero load	0.3744 l/km	[12]
χ	Carbon cost of vehicle per kilometer	Average fuel consumption * CO_2 emissions per kilometer = 1.3909 kg CO_2e/km	[12]
ϕ	CO_2 conversion per unit goods	0.87-1.28 kg CO_2e/kg	[13]
θ	Static Carbon Cost Coefficient	0.190 USD/kg	[14]

A. Equations

Number equations consecutively. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

$$a + b = \gamma \tag{10}$$

Be sure that the symbols in your equation have been defined before or immediately following the equation. Use "(10)", not "Eq. (10)" or "equation (10)", except at the beginning of a sentence: "Equation (10) is . . ."

B. LaTeX-Specific Advice

Please use "soft" (e.g., `\eqref{Eq}`) cross references instead of "hard" references (e.g., `(1)`). That will make it possible to combine sections, add equations, or change the order of figures or citations without having to go through the file line by line.

Please don't use the `{eqnarray}` equation environment. Use `{align}` or `{IEEEeqnarray}` instead. The `{eqnarray}` environment leaves unsightly spaces around relation symbols.

Please note that the `{subequations}` environment in LaTeX will increment the main equation counter even when there are no equation numbers displayed. If you forget that, you might write an article in which the equation numbers skip from (17) to (20), causing the copy editors to wonder if you've discovered a new method of counting.

BibTeX does not work by magic. It doesn't get the bibliographic data from thin air but from .bib files. If you use BibTeX to produce a bibliography you must send the .bib files.

LaTeX can't read your mind. If you assign the same label to a subsubsection and a table, you might find that Table I has been cross referenced as Table IV-B3.

LaTeX does not have precognitive abilities. If you put a `\label` command before the command that updates the counter it's supposed to be using, the label will pick up the last counter to be cross referenced instead. In particular, a `\label` command should not go before the caption of a figure or a table.

Do not use `\nonumber` inside the `{array}` environment. It will not stop equation numbers inside `{array}` (there won't be any anyway) and it might stop a wanted equation number in the surrounding equation.

C. Some Common Mistakes

- The word "data" is plural, not singular.
- The subscript for the permeability of vacuum μ_0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter "o".
- In American English, commas, semicolons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited,

such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)

- A graph within a graph is an "inset", not an "insert". The word alternatively is preferred to the word "alternately" (unless you really mean something that alternates).
- Do not use the word "essentially" to mean "approximately" or "effectively".
- In your paper title, if the words "that uses" can accurately replace the word "using", capitalize the "u"; if not, keep using lower-cased.
- Be aware of the different meanings of the homophones "affect" and "effect", "complement" and "compliment", "discreet" and "discrete", "principal" and "principle".
- Do not confuse "imply" and "infer".
- The prefix "non" is not a word; it should be joined to the word it modifies, usually without a hyphen.
- There is no period after the "et" in the Latin abbreviation "et al.".
- The abbreviation "i.e." means "that is", and the abbreviation "e.g." means "for example".

An excellent style manual for science writers is .

D. Authors and Affiliations

The class file is designed for, but not limited to, six authors. A minimum of one author is required for all conference articles. Author names should be listed starting from left to right and then moving down to the next line. This is the author sequence that will be used in future citations and by indexing services. Names should not be listed in columns nor group by affiliation. Please keep your affiliations as succinct as possible (for example, do not differentiate among departments of the same organization).

E. Identify the Headings

Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include Acknowledgments and References and, for these, the correct style to use is "Heading 5". Use "figure caption" for your Figure captions, and "table head" for your table title. Run-in heads, such as "Abstract", will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

Text heads organize the topics on a relational, hierarchical basis. For example, the paper title is the primary text head because all subsequent material relates and elaborates on this one topic. If there are two or more sub-topics, the next level head (uppercase Roman numerals) should be used and, conversely, if there are not at least two sub-topics, then no subheads should be introduced.

F. Figures and Tables

a) Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation "Fig. 1", even at the beginning of a sentence.

TABLE I
TABLE TYPE STYLES

Table Head	**Table Column Head**		
	Table column subhead	***Subhead***	***Subhead***
copy	More table copy[a]		

[a]Sample of a Table footnote.

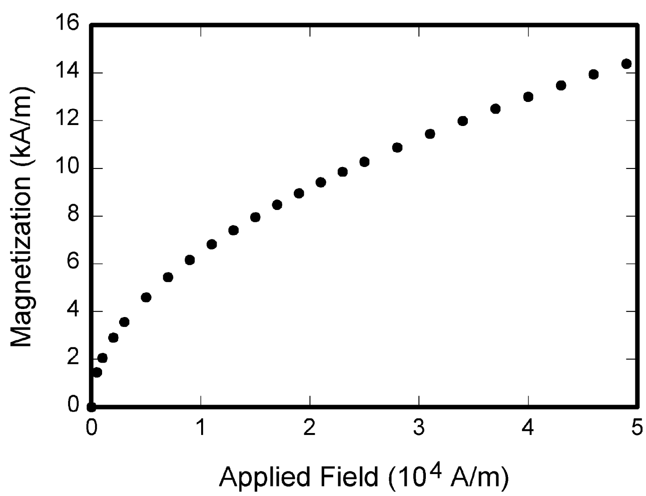

Fig. 1. Example of a figure caption.

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity "Magnetization", or "Magnetization, M", not just "M". If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write "Magnetization (A/m)" or "Magnetization {A[m(1)]}", not just "A/m". Do not label axes with a ratio of quantities and units. For example, write "Temperature (K)", not "Temperature/K".

ACKNOWLEDGMENT

The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression "one of us (R. B. G.) thanks ...". Instead, try "R. B. G. thanks...". Put sponsor acknowledgments in the unnumbered footnote on the first page.

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