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Review Article

A Survey of Transportation Problems

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This paper aims at being a guide to understand the different types of transportation problems by presenting a survey of mathematical models and algorithms used to solve different types of transportation modes (ship, plane, train, bus, truck, Motorcycle, Cars, and others) by air, water, space, cables, tubes, and road. Some problems are as follows: bus scheduling problem, delivery problem, combining truck trip problem, open vehicle routing problem, helicopter routing problem, truck loading problem, truck dispatching problem, truck routing problem, truck transportation problem, vehicle routing problem and variants, convoy routing problem, railroad blocking problem (RBP), inventory routing problem (IRP), air traffic flow management problem (TFMP), cash transportation vehicle routing problem, and so forth.

1. Introduction

The Transportation Problems (TP) is the generic name given to a whole class of problems in which the transportation is necessary. The general parameters of TP are as follows.

(A) *Resources*. The resources are those elements that can be transported from sources to destinations. Examples of discrete resources are goods, machines, tools, people, cargo; continuous resources include energy, liquids, and money.

(B) *Locations*. The locations are points of supply, recollection, depot, nodes, railway stations, bus stations, loading port, seaports, airports, refuelling depots, or school.

(C) *Transportation modes*. The transportation modes are the form of transporting some resources to locations. The transportation modes use water, space, air, road, rail, and cable. The form of transport has different infrastructure, capacity, times, activities, and regulations. Example of transportation modes are ship, aircraft, truck, train, pipeline, motorcycle, and others.

This paper aims to be a guide to understand the Transportation Problems (TP) by presenting a survey of the characteristics, the algorithms used to solve the problems, and the differences of the variants of the Transportation problems. Section 2 presents the classification and the general parameters of the Transportation Problems, Section 3 the variants of the Transportation Problems, and Section 4 the algorithms used to solve the Transportation Problems, and the last section presents the conclusions.

2. Transportation Problems

The transportation problems are to minimize the cost of carrying resources, goods, or people from one location (often know as sources) to another location (often know as destinations) using diverse types of transportation modes (ship, aircraft, truck, train, pipeline, motorcycle and others) by air,

water, road, aerospace, tube, and cable with some restrictions as capacity and time windows. The types of transportation problems are as follows.

2.1. Maritime Transportation. The maritime transportation carries resources over long distances from locations to other locations using maritime routes composed of oceans, coasts, seas, lakes, rivers, and canals of ships, or similar routes.

Resources. Bulk cargo (oil, coal, iron ore, grains, bauxite/alumina, phosphate, dry or liquid not packet); break-bulk cargo (bags, boxes, drums, all general cargoes that have been packaged); passenger vessels (passenger ferries, cruise ships); bulk carriers (liquid bulk vessels, dry bulk vessels, largest tankers of liquefied natural gas technology enabled); general cargo (vessels designed to carry nonbulk cargoes); Roll-on/Roll-off (RORO vessels, cars, trucks, and trains to be loaded directly on board); shrimp and seafood, hazardous materials; military-owned transportation resources; and goods (nonperishable goods, final manufactured goods, processed food, produce, livestock, intermediate goods, processed and raw materials).

Locations. Fishing port, warm water port, sea port, cruise port, cargo port, cruise home port, port of call, cargo ports, and oil platform.

Transportation Mode. Bulk carriers, container ships, tankers, reefer ships, Roll-on/Roll-off ships, coastal trading vessels, ferries, cruise ships, ocean liner, cable layer, tugboat, dredger, barge, general cargo ship, submarines, sailboat, jet boat, fishing vessels, service/supply vessels, barges, research ships, dredgers, and naval vessels.

2.2. Air Transportation. The air transportation carries resources over long, medium, and short distances from locations to other locations using air routes by aircrafts, charter flights, planes or others.

Resources. Military-owned transportation resources, passengers, air taxi service, goods, supplies and equipment, mail, troops, and others.

Locations. Airport terminals, heliport, helipads, helistop, Helideck and Helispot, and area of military operations.

Transportation Mode. Fixed-wining aircraft, airplane, gyroplane, recreational aircraft, military cargo aircraft, helicopters, zeppelins, personal air transportation with jet packs and blimps, military transport helicopters, tactical and strategic airlift, air ambulance, and aerial refuelling.

2.3. Land Transportation. The land transportation carries resources over long, medium, and short distances from locations to other locations using the road routes by vehicle or similar means of land transportation.

Resources. Military-owned transportation resources, goods, people, hazardous materials, waste, or money.

Locations. Pizza restaurant, post office, university, schools, gas stations, warehouse, stores, markets, fish market, dump, bottling plants, malls, depots, houses, Landfill, incineration plant, waste container, banks, and others.

Transportation Mode. Buses; trucks; motorcycles; bicycles; cars and pickups; box trucks and dock highs; cargo and sprinter vans; less than truck Load (LTL); full truck load (FTL); flatbeds; reefers (refrigerated units); longer combination vehicles (LCV) with double semitrailer, recovery vehicle, scooters, and pedestrians; main battle tank; infantry fighting vehicles; armored personnel carriers; light armored vehicles; self-propelled artillery and anti-Air mine protected vehicles; combat engineering vehicles; prime movers and trucks; unmanned combat vehicles; military robot; joint light tactical vehicle (JLTV), utility vehicle, refrigerator truck, landfill compaction vehicle, garbage truck, waste collection vehicle; armored cash transport car; and security van.

2.4. Rail Transportation. Rail transport carries resources over long, medium, and short distances by way of wheeled vehicles running on rail track or railway.

Resources. Military-owned transportation resources, goods, passenger, containers, and bulks.

Locations. Stations, transit centre locations, park and ride locations, railway station, railroad station, goods stations, large passenger stations, smaller stations, early stations, central stations, railway platform (bay platform, side platform, island platform), metro station, train station, tram stop, station facilities, terminal, interchange station, tunnel stations, metro depot, maintenance depot, and light rail depot.

Transportation Mode. Trains, metro, subway, vactrain, magnetic levitation train, ground effect train, U-Bahn and S-Bahn, intercity trains, intercity rail, high-speed rail, high speed train, locomotive, pacer (train), freight car, goods train, railway passenger car, coach passenger car, intermodal freight transport, refrigerated railroad cars, light rail vehicles, suburban railway, urban railway, rapid transit, underground railway, elevated railway, metropolitan railway, carbody, ballast tamping machine, long welded rail cars, cleaning trains, concreting trains, rail grinders, ballast tamping machines, track recording cars, and rail grinders.

2.5. Space Transportation. Space transportation carries resources from locations to other locations by suborbital and orbital flights in the upper atmosphere and the space by Hall Electric propulsion or similar.

Resources. Military-owned transportation resources, cargo or passengers, personnel, fuel (LH2), oxydizer (LOX), and propellants (LOX and LH2 at given mixture ratio).

Locations. Earth spaceport (ES), Low Earth Orbit (LEO), Geostationary Earth Orbit (GEO), Lagrange Point L1 (L1), Low Lunar Orbit (LUO), Lunar SpacePort (LUS), Lagrange Point L2 (L2), Planetary escape mission (PLA), Mars Spaceport

(MAS), Space Operations Center, Lunar Service Center, Lunar Propellant Production Facility, and others.

Transportation Mode. Rocket-powered aircraft, nuclear powered aircraft, spacecraft, space shuttle, space, space planes, rockets, missiles, and advanced Hall electric propulsion, crew exploration vehicle (CEV), automated transfer vehicle (ATV), evolved expendable launch (EELV), National Aerospace Plane (NASP), transatmospheric vehicle (TAV), orbital space plane, next generation launch technology, winged shuttle (WSLEO), expendable interorbital ferry vehicle (EIOFV), reusable interorbital ferry vehicle (RIOFV), and spaceship.

2.6. Pipeline and Cable Transportation. Pipeline and cable transportation carries resources from locations to other locations by pipe and vehicles pulled by cables.

Resources. Water, energy, electricity, petroleum products, telecommunications, chemicals, slurry coal, natural gas, sewage, beer, biofuels (ethanol and biobutanol), hydrogen, skiers, and passenger lift.

Locations. Residential and commercial areas, treatment plant, processing facility, gas stations, pump stations, terminals, tanks, storage facilities, partial delivery stations, inlet station, injection station, block valve station, regulator station, final delivery station, floors (levels, decks) of a building, vessel, or other structures.

Transportation Mode. Pipelines (gathering pipelines, transportation pipelines, distribution pipelines), ducts, oil pipelines, gas pipeline, transmission lines, electrical substations, pole-mounted transformed, generation stations, distribution systems, electricity transmission system, tubes, aerial lifts (aerial tramway, chairlift, funitel, gondola lift, ski lift), surface cable transportation (cable car, cable ferry, funicular, surface lift), and vertical transportation (Elevator).

2.7. Intermodal Transportation. Intermodal transportation carries resources from locations to other locations using maritime, air, road, rail, cable, tube, and/or space routes by ships or similar, aircraft or similar, vehicle or similar, trains or similar, Hall Electric propulsion or similar, pipe and/or vehicles pulled by cables.

3. Variants of the Transportation Problems

3.1. Maritime Transportation Problems. In the specialized literature there exist various variants of the Maritime Transportation Problems. The main variants of the Maritime Transportation Problems are RoRo ship stowage problem (RSSP) [1]; ship routing problem (SRP) [2, 3]; ship routing problem of tramp shipping (SRPTP) [2]; inventory constrained maritime routing and scheduling problem for multicommodity liquid bulk [4]; vessel fleet scheduling/allocation [5, 6]; cargo routing problem [4]; maritime inventory ship routing problem [7]; oil-tanker routing and scheduling problem [8, 9]; maritime oil transportation problem [10]; industrial ship scheduling problem [7]; industrial ship scheduling problem with fixed cargo sizes [7]; tramp ship scheduling problem [7]; single product inventory ship routing problem [7]; multiple product inventory ship routing problem [7]; tramp ship routing and scheduling problem with speed optimization [11]; and maritime platform transport problem of solid, special and dangerous waste [12].

The RoRo ship stowage problem (RSSP) [1] to decide (which optional cargoes to carry, how stow all cargoes on board the ship, all long-term contracts are fulfilled) upon a deck configuration with respect of the height. The objective is to maximize the sum of revenue from optional cargoes minus penalty costs incurred when having to move cargoes. The mathematical model of RSSP [1] is formed by (1)–(18):

$$\max \sum_{c\in C_0} R_c^F Zc - \sum_{c\in C}\sum_{c'\in Cc}\sum_{d\in D}\sum_{l\in L} C_c^M W_{dlcc'}, \tag{1}$$

$$C_c^L \cdot y_{dlpc} - L_d \cdot x_{dlpc} \le 0, \quad d \in D,\ l \in L,\ c \in C,\ p \in Pc, \tag{2}$$

$$C_c^H \cdot x_{dlpc} - (h_{d+1} - h_d) \le 0, \quad d \in D,\ l \in L,\ c \in C,\ p \in Pc, \tag{3}$$

$$C_c^W \cdot x_{dlpc} - v_{dl} \le 0, \quad d \in D,\ l \in L,\ c \in C,\ p \in Pc, \tag{4}$$

$$y_{d,l,p+1,c} - y_{dlpc} = 0, \quad p \in Pc \setminus \left\{P_c^U - 1\right\},\ |Pc| \ge 2, \tag{5}$$

$$\sum_{l\in L} V_{dl} = W_d, \quad d \in D, \tag{6}$$

$$\sum_{d\in D}\sum_{l\in L} y_{dlpc} = Nc, \quad c \in C_M,\ p \in Pc, \tag{7}$$

$$\sum_{d\in D}\sum_{l\in L} y_{dlpc} = NcZc, \quad c \in C_0,\ p \in Pc, \tag{8}$$

$$\sum_{c\in C} C_c^L \cdot y_{dlpc} \le L_d, \quad d \in D,\ l \in L,\ p \in P, \tag{9}$$

$$-T^{\mathrm{MAX}} \le \sum_{c\in C}\sum_{d\in D}\sum_{l\in L} C_c^V \cdot y_{dlpc} \cdot \overline{X}_{dl} \le T^{\mathrm{MAX}}, \quad p \in P, \tag{10}$$

$$W^S Y^S + \sum_{c\in C}\sum_{d\in D}\sum_{l\in L} C_c^V y_{dlpc} \bar{Y}_d \le \left(W^S + \sum_{c\in C}\sum_{d\in D}\sum_{l\in L} C_c^V y_{dlpc}\right) Y^{\mathrm{MAX}}, \quad p \in P, \tag{11}$$

$$z_{dl,P_c^L,c'} \le 1 + w_{dlcc'}, \quad d \in D,\ l \in L,\ c \in C,\ c' \in Cc, \tag{12}$$

$$D_d^L \le h_d \le D_d^U, \quad i \in D^R, \tag{13}$$

$$v_{dl} \ge 0, \quad d \in D,\ l \in L, \tag{14}$$

$$w_{dlcc'} \in \{0,1\}, \quad d \in D,\ l \in L,\ c \in C,\ c' \in Cc, \tag{15}$$

$$w_{dlpc} \in \{0,1\}, \quad d \in D,\ l \in L,\ c \in C,\ p \in Pc, \tag{16}$$

$$z_c \in \{0,1\}, \quad c \in C, \tag{17}$$

$$y_{dlpc} \ge 0 \text{ and integer}, \quad d \in D,\ l \in L,\ c \in C,\ p \in Pc, \tag{18}$$

where C is the set of all cargoes, C_M is the set of all mandatory cargoes, Co is the set of all optional cargoes, D is the set of all decks, L is the set of all potential lanes on each decks, P is the set of all ports (except the last port on the route), Pc is the set of ports from loading port of cargo c to the port before the unloading port of cargo c, Cc is the set of cargoes c', W_d is the width of deck d, L_d is the length of deck d, C_c^L is the length of one vehicle in cargo c, C_c^W is the width of one vehicle in cargo c, C_c^H is the height of one vehicle in cargo c, P_c^L is the loading port of cargo c, P_c^U is the unloading port of cargo c, D_d^L is the lower bound for where deck d can be placed, D_d^U is the upper bound for where deck d can be placed, R_c^F is the revenue for transporting optional cargo c, Nc is the number of vehicles in cargo c, C_c^M is the cost incurred if cargo c needs to be moved, T^{MAX} is the maximum allowable torque on the ship from the cargo, Y^{MAX} is the highest allowable center of gravity of the laden ship, C_c^V is the weight of one vehicle from cargo c, WS is the lightweight of the ship, Y^S is the vertical distance from the ship's bottom deck to its center of gravity when empty, $\overline{X}_{dl}$: approximated horizontal distance of lane l on deck d from the ship's center of gravity, $\overline{Y}_d$ is the approximated vertical distance of deck d from the ship's bottom deck, c is the cargo, d is the deck, l is the lane, and p is the port.

In (1) the objective is to maximize the sum of revenue from optional cargoes minus penalty costs incurred when having to move cargoes. Equation (2) links the binary indicator variables x_{dlpc} for if lane l on deck d is used from port p to $p+1$ by cargo c, to the integer variables y_{dlpc} for how many vehicles from cargo c that are stowed in lane l on deck d from port p to $p+1$. Equation (3) ensures that there is enough vertical space on the deck where the cargoes are placed. Equation (4) shows the sufficient width of the lanes. Equation (5) makes sure that once a cargo has been placed, it remains unmoved until it is unloaded. In (6), the partitions of decks into lanes are restricted. Equations (7) and (8) link the integer variables y_{dlpc} for how many vehicles from cargo c, that is, stowed in lane l on deck d from port p to $p+1$, to the number of vehicles from cargo c, that is, carried, for respectively mandatory and optional cargoes. Equation (9) ensures that the length of a lane is not violated by the vehicles stowed in that lane. Equations (10) and (11) are restrictions on ship stability calculations and involve nonlinear equations. Equation (10) imposes that the torque from the cargo on the ship should be within the allowable limit to avoid rolling. The constants view the $\overline{X}_{dl}$ are approximations of the horizontal distance of a lane to the center of the ship, with negative values indicating a possible tilt to the port side and positive values indicating a tilt to the starboard side. Equation (11) ensures that the maximum allowable vertical distance Y^{MAX} from the ship's bottom deck to the ship's centre of gravity when loaded is not exceeded. When vehicles from cargo c are loaded in front of vehicles from cargo c' and cargo c' is unloaded before cargo c, there is an inconvenience as vehicles from cargo c must be moved out of the way. Equation (12) makes sure that a corresponding penalty is added to the objective function. Equation (13) provided upper and lower bounds on the deck heights. Equation (14) ensured the nonnegativity of lane width. Equations (15), (16), and (18) make sure that the variables $w_{dlc'}$, x_{dlpc}, and z_c take binary values. And (18) imposes nonnegativity and integrality on the number of vehicles carried in each lane.

3.2. Air Transportation Problems. In the specialized literature there exist various variants of the Air Transportation Problems. The main variants of the Air Transportation Problems are air traffic flow management problem (TFMP) [13], multi-airport ground holding problem (MAGHP) [14, 15], air traffic flow management rerouting problem (tfmrp) [16], helicopter routing problem (HRP) [17], airline crew scheduling problem [18], and oil platform transport problem [19].

The general problem of Air Transportation is represented in the mathematical model described by Li et al. [20, 21], which presents an objective that is to minimize the overall total cost which consists of the total transportation cost of the orders allocated to normal flight capacity, the total transportation cost for the orders allocated to special flight capacity, and the total delivery earliness tardiness penalties cost. The mathematical programming formulation of the model is shown as follows:

$$\begin{aligned}\min & \sum_{i=1}^{N}\sum_{f=1}^{F} NC_f X_{if} + \sum_{i=1}^{N}\sum_{f=1}^{F} SC_f Y_{if} \\ & + \sum_{i=1}^{N}\sum_{f=1}^{F} \alpha_i * \max\left(0, d_i - A_f\right) * \left(X_{if} + Y_{if}\right) \\ & + \sum_{i=1}^{N}\sum_{f=1}^{F} \beta_i * \max\left(0, A_f - d_i\right) * \left(X_{if} + Y_{if}\right),\end{aligned} \tag{19}$$

$$LN * X_{if} * \left|\mathrm{Des}_i - \mathrm{des}_f\right| < 1, \quad i = 1, \ldots, N;\ f = 1, \ldots, F, \tag{20}$$

$$LN * Y_{if} * \left|\mathrm{Des}_i - \mathrm{des}_f\right| < 1, \quad i = 1, \ldots, N;\ f = 1, \ldots, F, \tag{21}$$

$$\sum_{i=1}^{N} X_{if} \le N_{\mathrm{Cap}_f}, \quad f = 1, \ldots, F, \tag{22}$$

$$\sum_{i=1}^{N} Y_{if} \le S_{\mathrm{Cap}_f}, \quad f = 1, \ldots, F, \tag{23}$$

$$\sum_{f=1}^{F} \left(X_{if} + Y_{if}\right) = Q_i, \quad i = 1, \ldots, N, \tag{24}$$

$$\begin{aligned}\sum_{i=1}^{N} & \left(\frac{\max\left(0, \left(\sum_{f'=1}^{f} X_{if'} + Y_{if'}\right) - 0.5\right)}{\left(\sum_{f'=1}^{f} X_{if'} + Y_{if'}\right) - 0.5} \right) p_i \\ & \le D_f, \quad f = 1, \ldots, F,\end{aligned} \tag{25}$$

$$X_{if}, Y_{if} = \text{Non-negative Integer Variables}, \tag{26}$$

where i, i', and j are the order or job index, $i = 1, 2, \ldots, N$; f or f' is the flight index, $f = 1, 2, \ldots, F$; k is the destination

index, $k = 1, 2, \ldots, K$; D_f is the departure time of flight f at the local airport; Af is the arrival time of flight f at the destination; NC_f is the transportation cost for per unit product when allocated to normal capacity area of flight f; SC_f is the transportation cost for per unit product when allocated to special capacity area of flight f; N_{Cap_f} is the available normal capacity of flight f; S_{Cap_f} is the available special capacity of flight f; Q_i is the quantity of order i; α_i is the delivery earliness penalty cost (/unit/h) of order i; β_i is the delivery tardiness penalty cost (/unit/h) of order i; d_i is the due date of order i; X_{if} is the quantity of the portion of order i allocated to flight $f's$ normal capacity area; Y_{if} is the quantity of the portion of order i allocated to flight $f's$ special capacity area; Des_i is the order $i's$ destination; Des_f is the flight $f's$ destination; LN is a large positive number; p_i is the processing time of order i. The decision variables (X_{if}, Y_{if}, and Z_{if}) are nonnegative integer.

The objective of (19) is to minimize total cost which consists of transportation cost of orders allocated into normal flight capacity, transportation cost of orders allocated into special flight capacity, the delivery earliness penalty costs of orders, and the delivery tardiness penalty costs of orders. Equations (20) and (21) ensure that if order i and flight f have different destination, order i cannot be allocated to flight f. Equation (22) ensures that the quantity of the portion of order i allocated into flight f consists of quantities of the portion of order i allocated into normal capacity area of flight f and the portion of order i allocated to special capacity area of flight f. Equation (23) ensures that the normal capacity of flight f is not exceeded. Equation (24) ensures that the special capacity of flight f is not exceeded. Equation (25) ensures that order i is completely allocated. Equation (26) ensures that allocated orders do not exceed production capacity. It ensures that allocated quantity can be supplied by sufficient assembly capacity.

3.3. Land Transportation Problems. In the specialized literature there exist various variants of the Land Transportation Problems. The main variants of the Land Transportation Problems are bus terminal location problem (BTLP) [22], convoy routing problem (CRP) [23], inventory routing problem (IRP) [24], inventory routing problem with time windows (IRPTW) [25], school bus routing problem (SBRP) [26], tour planning problem (TPP) [27], truck and trailer routing problem (TTRP) [28], vehicle departure time optimization (VDO) problem [29], vehicle routing problem with production and demand calendars (VRPPDC) [30], bus terminal location problem (BTLP) [22], bus scheduling problem [31], delivery problem [32], combining truck trip problem [33], open vehicle routing problem [34], transport problem [35], truck loading problem [36], truck dispatching problem [37], convoy routing problem [23], multiperiod petrol station replenishment problem [38], petrol station replenishment problem [39], vehicle routing problem [40], capacitated vehicle routing problem (CPRV) [40], multiple depot vehicle routing problem (MDVRP) [40], periodic vehicle routing problem (PVRP) [40], split delivery vehicle routing problem (SDVRP) [40], stochastic vehicle routing problem (SVRP) [40], vehicle routing problem with backhauls (VRPB) [40], vehicle routing problem with pick-up and delivering (VRPPD) [40], vehicle routing problem with satellite facilities [40], vehicle routing problem with time windows (VRPTW) [40], waste transport problem (WTP) [41], cash transportation vehicle routing problem [42], team orienteering problem [43], military transport planning (MTP) [44], petrol station replenishment problem with time windows [45].

The school bus routing problem (SBRP) is a significant problem in the management of school bus fleet for the transportation of students; each student must be assigned to a particular bus which must be routed in an efficient manner to pick up (or return home) each of these students [26]. The characteristics of SBRP [46] are number of schools (single or multiple), surrounding services (urban or rural), problem scope (morning, afternoon, both), mixed Load (allowed or no allowed), special-education students (considered or not considered), fleet mix (homogeneous fleet or heterogeneous fleet), objectives (number of buses used, total bus travel distance or time, total students riding distance or time, student walking distance, load balancing, maximum route length, Child's time loss), constraints (vehicle capacity, maximum riding time, school time windows, maximum walking time or distance, earliest pick-up time, minimum student number to create a route). The mathematical model of SBRP [47] is formed by (27)–(34):

$$\min z = \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=1}^{M} C_{ij}X_{ijk}, \tag{27}$$

$$\sum_{k=1}^{M}\sum_{j=0}^{n} X_{ijk} = 1, \quad i = 1, 2, \ldots, n, \tag{28}$$

$$\sum_{k=1}^{M}\sum_{i=0}^{n} X_{ijk} = 1, \quad j = 1, 2, \ldots, n, \tag{29}$$

$$\sum_{k=1}^{M}\sum_{j=0}^{n} X_{0jk} = \sum_{k=1}^{M}\sum_{i=0}^{n} X_{i0k} = M, \tag{30}$$

$$\sum_{j=0}^{n} X_{ijk} = \sum_{j=0}^{n} X_{jik}; \quad i = 1, 2, \ldots, n;\ k = 1, 2, \ldots, M, \tag{31}$$

$$U_{ik} + U_{jk} + (n - m + 1)\, X_{ijk} \le (n - M); \quad 1 \le i,\ j \le n,\ i \ne j,\ k = 1, 2, \ldots, M, \tag{32}$$

$$\sum_{i=0}^{n}\sum_{j=0}^{n} X_{ijk} q_i \le Q; \quad k = 1, 2, \ldots, M, \tag{33}$$

$$\sum_{i=1}^{n}\sum_{j=0}^{n} X_{ijk} t_{ij} \le \tau; \quad k = 1, 2, \ldots M. \tag{34}$$

School buses are centrally located and have to collect waiting students at n pick-up points and to drive them to school. The number of students that wait in pickup point i is q_i, ($q_i > 0$, $i = 1, 2, \ldots, n$). The capacity of each bus is limited to Q

students ($q_i \leq Q$). The objective function of the School Bus Problem is composed of two costs: (a) cost incurred by the number of buses used, (b) driving cost (fuel, maintenance, drivers salary, and others), subject to operational constraints, Costs (a) or (b) have to be minimized. For a given M of buses, let X_{ijk}, $i, j = 0, 1, 2, \ldots, n, k = 1, 2, \ldots, M$ be variables that attain the value 1 if pickup points i and j are visited by the kth bus and pickup point j is visited directly after i. Otherwise, X_{ijk} is 0. Let U_{ik}, $i = 0, 1, \ldots, n, k = 1, 2, \ldots, M$ be variables that may attain any value. The objective of the SBRP is to find variables X_{ijk} and U_{ik} that minimize z. Where C_{ij} = cost of driving from point i to point j, C_{ij} is a function of the distance between i and j and the driving time, $C_{ij} = \begin{cases} C_{ij} & \forall i, j,\ i \neq j, \\ \infty & \forall i = j, \end{cases}$, t_{ij} = driving time from point i to point j, q_i = a quantity to be loaded (or unloaded) at i, k = set of constraints characterized by the nature of the problem, where $k = (1, 2, \ldots, K) \in K$. The three-dimensional assignment problem given in ((28), (29), (30), (31), and (32)) could be transformed into a regular assignment problem by duplicating $M - 1$ times the row and column corresponding to city 0 and obtaining an assignment problem with dimensions $(n + M)$ by $(n + M)$. Constraints ensure the formation of exactly M tours, where each one passes through the school. The restriction of capacity is in (33) and the constraint of time is in (34).

SBRP is formulated as mixed integer programming or nonlinear mixed integer programming models. The researchers are often not used to directly solve the problems; they use a relaxation of the problem to solve it. School bus schedules are important because they reduce costs to the universities or schools and bring added value to the students to have a quality transport.

3.4. Rail Transportation Problems. In the specialized literature there exist various variants of the Rail Transportation Problems. The main variants of the Rail Transportation Problems are train formation problem (tfp) [48], locomotive routing problem [49], tour planning problem by rail (tpp) [50], rolling stock problem (rsp) [51], yard location problem [52], and train dispatching problem [53].

Train dispatching transportation problem, train meet-and-pass problem, or train timetabling problem is the process of handling a given set of desired train operating schedules and merging these requests as best as possible to a valid timetable [53]:

$$\max w^T x, \tag{35}$$

$$\sum_i x_{bt}^i \leq 1, \quad \forall b \in B,\ t = 1, \ldots, T, \tag{36}$$

$$x^i \in T^i, \quad \forall i \in I, \tag{37}$$

Equations (36) and (37) are the track capacity constraint, these equations ensure ensures that no two trains are scheduled that occupy the block $b \in B$ at the same moment t. Each binary variable x_{bt}^i takes the value of one if and only if the train i occupies the block b. The set T contains all vectors that result in technically and logistically feasible schedules for the train i.

3.5. Space Transportation Problems. In the specialized literature there exist various variants of the Space Transportation Problems. The main variants of the Space Transportation Problems are generalized location routing problem with space exploration or generalized location routing problem with profits (GLRPPs) [54], Earth-Moon supply chain problem [55], interplanetary transfer between halo orbits [56], and Hill's restricted three-body problem (Hill's R3BP) [57].

The Earth-Moon supply chain problem [55] considers the problem of delivering cargo units of water from low Earth orbit to lunar orbit and the lunar surface. The formulation requires that the architectural characteristics of the vehicle used to transport the packages to the destinations and the paths the vehicles travel are to be determined concurrently. The problem is solved using both traditional design optimization methods and a concurrent design optimization method:

$$\min J = \sum_{i=1}^{n} \sum_{j=i}^{n} \sum_{k=j}^{n} n_{ijk} m_{wijk}, \tag{38}$$

$$\sum_{j=1}^{n} \sum_{k=j}^{n} x_{1jk} = s(1), \tag{39}$$

$$\sum_{i=1}^{n} \sum_{j=i}^{k} x_{ijk} = d(k), \quad \forall k = 2, \ldots, n, \tag{40}$$

$$\sum_{k=j}^{n} x_{ijk} \leq \sum_{k=j}^{n} C_{ijk} n_{ijk}, \quad \forall j, \tag{41}$$

$$x_{ijk} \leq C_{ijk} n_{ijk}, \quad \forall i, j, k\ j \neq k, \tag{42}$$

$$x_{ijj} \leq \sum_{k=j}^{n} c_{ijk} n_{ijk}, \quad \forall i, j, \tag{43}$$

$$1 \leq \sum_{i=1}^{m} S_i \leq m, \quad S_i \in \{0, 1\}, \tag{44}$$

$$f_{i+1} - f_i \leq p S_i, \quad \forall 1, \ldots, m - 1, \tag{45}$$

$$\frac{m_{pl}}{m_0} = \prod_{i=1}^{N_{\text{stage}}} (1 + \alpha_i) \exp\left(\frac{-\Delta V_i}{I_{sp_i} g_0}\right) - \alpha_i; \quad N_{\text{stage}} = \sum_{i=1}^{m} S_i, \tag{46}$$

$$m_w = m_{pl} C \left(\frac{m_0}{m_{pl}} - 1\right), \tag{47}$$

where (i, j, k) is the transfer starting at node i traveling to node j and terminating at node k, n_{ijk} is the number of vehicles on route (ijk), C_{ijk} is the capacity of vehicle on route (i, j, k), m_{0ijk} is the vehicle initial mass, m_{w1k} is the vehicle wet mass, x_{ijk} is the number of packets that leave node i equal to the supply at node i ($s(i)$), and ΔV is the velocity change.

Equation (38) defines the main objective. The main objective of the system is to minimize the initial mass of the

transportation system architecture. The n_{ijk} is the number of vehicles that start at node i, travel to node j, and then terminate at node k and m_{0ijk} is the initial mass of a vehicle on route (i, j, k). The initial vehicle mass (m_{0ijk}) is determined by the vehicle capacity for each route C_{ijk} and the actual initial mass is the wet mass (m_{wijk}) plus the amount of payload carried on that vehicle. Each route carries x_{ijk} packages that each weighs m_{pl}. For each route, the initial mass is defined as $n_{ijkm}w_{ijk} + x_{ijk}m_{pl}$ and this is summed over all routes. The summation of x_{ijk} over all routes is simply the amount of supply, which is a constant. Equation (39) contains a restriction of the network subsystem that determines the actual package flows from Low Earth Orbit (LEO) to the destination nodes. To ensure a feasible package flow, we must define the supply, demand, and capacity constraints for the space network. The supply constraints ensure that the number of packages (x_{ijk}) that leave node i is equal to the supply at node i ($s(i)$). Equation (40) ensures that the number of packages that arrive at node k is equal to the demand of node k ($d(k)$). Equation (41) ensures that the vehicle has enough capacity to accommodate the packages. Equations (42) and (43) contain the upper bound on the number of packages on each route. Equation (44) defines a binary decision variable, S_i, which is equal to one if we stage after burn i and zero otherwise. It can stage at most m times, where m is the total number of burns required for that route. It assumes that the vehicle stages after the last burn ($S_m = 1$). Equation (45) defines the variable f_i to represent the type of fuel used during stage i. The variable f_i can take on integer values up to the number of different types of fuel available (the model do not allow hybrid stages, to ensure that the same type of fuel is used for consecutive burns in a single stage). First in (46) the total number of stages is computed (N_{stage}). Next using the staging locations, the amount of ΔV required for each stage (ΔV_i) can be defined. The amount of ΔV in a given stage is the sum of the ΔV for each burn up to and including the first burn for which the vehicle stages ($S_i = 1$). Finally, the initial mass (m_0) of the vehicle is calculated using the rocket equation. Equation (47) computes the vehicle wet mass (the mass of the structure and fuel without the payload mass).

3.6. Pipeline and Cable Transportation Problems. In the specialized literature there exist various variants of the pipeline and cable Transportation Problems. The main variants of the Pipeline and Cable Transportation Problems are water distribution network (WDN) [58, 59], bulk energy transportation networks [60], generalized network flow model or multiperiod generalized minimum cost flow problem [61, 62], water flow and chemical transport [63], CO_2 pipeline transport [64, 65].

The coal, gas, water, and electricity production and transportation systems model [66] uses the fact that each of these subsystems depends on the integrated operation of a network together with a market, and it captures the strong coupling within and between the different energy subsystems. The mathematical framework using a network flow optimization model with data characterizing the actual national electric energy system as it exists today in the United States [66] is formed by (48)–(52):

$$\begin{aligned}\min z = {} & \sum_{\forall t}\sum_{\forall p} c_p \cdot E_{ppt} + \sum_{\forall t}\sum_{\forall g} g_g \cdot E_{ggt} + \sum_{\forall t}\sum_{\forall s} S_s \cdot E_{sst} \\ & + \sum_{\forall t}\sum_{\forall p}\sum_{\forall g}\sum_{\forall m} t_{pgmt} \cdot E_{pgmt} \\ & + \sum_{\forall t}\sum_{\forall p}\sum_{\forall s}\sum_{\forall m} t_{psmt} \cdot E_{psmt} \\ & + \sum_{\forall t}\sum_{\forall s}\sum_{\forall g}\sum_{\forall m} t_{sgmt} \cdot E_{sgmt} + \sum_{\forall t}\sum_{\forall r} t_{rt} \cdot E_{rt},\end{aligned} \tag{48}$$

$$E_{ppt} - \sum_{\forall g}\sum_{\forall m} E_{pgmt} - \sum_{\forall s}\sum_{\forall m} E_{psmt} = 0, \quad \forall p,\ \forall t, \tag{49}$$

$$-E_{sst} + E_{ss,t-1} + \sum_{\forall p}\sum_{\forall m} E_{psmt} - \sum_{\forall g}\sum_{\forall m} E_{sgmt} = 0, \quad \forall s,\ \forall t, \tag{50}$$

$$\sum_{\forall s}\sum_{\forall m} E_{sgmt} + \sum_{\forall p}\sum_{\forall m} E_{pgmt} - E_{ggt} = 0, \quad \forall g,\ \forall \text{t}, \tag{51}$$

$$\sum_{\forall i} \eta_{ij} \cdot E_{ij} - \sum_{\forall k} E_{jk} = E_{j,\text{output}} - E_{j,\text{input}}. \tag{52}$$

The objective function (48) is equal to the total production cost + total generation cost + total storage cost + total transportation cost for the gas and coal subsystems, subject to energy balance at the production nodes (49), energy balance at the storage nodes (50), energy balance at the generation nodes (51), and energy balance at the electric transmission nodes (52), where Z is the total cost (production, storage and transportation) of the energy over 1 year at weekly intervals; p is the production node; g is the generation node; d is the electric transmission mode; s is the storage node; m is the transportation mode; r is the transmission line, c_p, g_g, and s_s are the per unit cost of extraction, generation (without including the fuel cost to avoid duplication), and storage; t_{pgmt}, t_{psmt}, and t_{sgmt} are the per unit cost of gas or coal transportation from a production or storage node to a storage or generation node, using the transportation mode m at time t; t_{rt} is the per unit cost of the electric energy transported by the transmission line r at time t; E_{ppt} is the total energy produced in the production node p during time t; E_{sst} is the energy at the storage facility s at the end of time t; E_{ggt} is the total energy arriving to the generation facility g at time t; E_{pgmt}, E_{psmt}, and E_{sgmt} are the amount of energy going from a production or storage node to a storage or generation node, shipped using the transportation mode m during the time t; E_{rt} is the amount of electric energy flow in the transmission line r during the time t; E_{dt} is the forecasted energy demand in the electric node d during the time t; $E_{ss,0}$ and $E_{ss,T}$ are the energy in the storage facility s at the beginning and end of the scheduling horizon; η_r is the efficiency of the energy transmission line r; E_{ij} is the energy from node i to node j; E_{jk} is the energy from node j to node k; $E_{j,\text{input}}$ is the energy

Table 1: Related Works.

Algorithm	Problem	Contribution
Multiphase heuristic [72]	Multiperiod petrol station replenishment problem	A heuristic with a route construction and truck loading procedures, a route packing procedure, and two procedures enabling the anticipation or the postponement of deliveries for the MPSRP.
Exact algorithm [45]	Petrol station replenishment problem	The algorithm decomposes the problem into truck loading problem and a routing problem.
Genetic algorithm [73]	Air transportation scheduling problem	The Taguchi experimental design method is applied to set and estimate the proper values of gas parameters.
Simulated annealing based heuristic algorithms [74]	Air transportation	The problem is formulated as a parallel machine scheduling problem with earliness penalties.
Simulated annealing algorithm [75]	Arrival flight delays problem	Based on the characteristic of the flights and the thinking of system optimization, this paper builds up dynamic optimizing models of the flight delays scheduling with the objective function of delay cost.
Greedy algorithm [76]	Single-airport ground-holding problem (SAGHP)	A dynamic programming formulation with a corresponding backward solution algorithm.
Coevolutionay genetic algorithm [14, 15]	Multiairport ground-holding problem	Survey model with dynamic capacity in details.
Column generation based heuristic algorithm [77]	Helicopter routing problem	A MIP based heuristic with an add column generation procedures that improve the solution quality for the Brazilian State Oil Company (Petrobras).
Heuristic algorithm [42]	Cash transportation vehicle routing problem	A solution algorithm based on a problem decomposition/collapsing technique, coupled with the use of a mathematical programming software.
Tabu search [78]	Helicopter routing problem	Three routing policies are considered: a direct routing policy, a Hamiltonian routing policy, and a general routing policy.
Hub-and-spoke configuration [79]	Helicopter routing problem	Mathematical model and theoretical results for route planning with a safety-based objective for helicopter routing in the Norwegian oil industry.
Genetic algorithm [80]	Multiobjective helicopter routing problem	A variation of the cluster-first route-second method for routing helicopters
Transgenic algorithm [81]	Vehicle routing problem with time windows	Horizontal gene transfer based on the transformation mechanism and an intelligent mutation operator called Symbion operator.
Vertical transfer algorithm [82]	School bus routing problem	A computer algorithm based on the mechanism of vertical gene transfer.
Particle swarm optimisation [83]	Vehicle routing problem with time windows	An improved hybrid particle swarm optimisation (IHPSO) method with some postoptimisation procedures.
Genetic algorithm [84]	Vehicle routing problem with time windows	Population preselection operators.
Genetic algorithm [85]	Vehicle routing problem with time windows	A physical parallelisation of a distributed real-coded genetic algorithm and a set of eight subpopulations residing in a cube topology.
Tabu search [86]	Vehicle routing problem with time windows and multidepot (VRPTW)	A unified Tabu search heuristic.
Simulated annealing [87]	Vehicle routing problem with time windows	A two-phase system (global neighbourhoods and local neighbourhood) of a parallel simulated annealing.
Simulated Annealing [88]	Vehicle routing problem with time windows	2 interchanges with the best-accept-strategy.
Evolutionary Algorithm [89]	Vehicle routing problem with time windows	An individual representative called the strategy parameter used in the recombination and mutation operators.
Tabu Search [90]	Vehicle routing problem with time windows	The Tabu search with a neighbourhood of the current solution created through an exchange procedure that swaps sequences of consecutive customers.
Genetic Algorithm [91]	Vehicle routing problem with time windows	A genetic routing system or GENEROUS based on the natural evolution paradigm.
GRASP [92]	Vehicle routing problem with time windows	A two-phase greedy randomised adaptive search to solve VRPTW.
Branch-and-Bound method [93]	Vehicle routing problem with time windows	A Branch-and-Bound method to solve VRPTW.

Table 1: Continued.

Algorithm	Problem	Contribution
A rural routing heuristic [94]	School bus routing problem	Constructing the initial route and then improving it by using a fixed tenure Tabu search algorithm.
GRASP [95]	School bus routing problem	The solution method starts with a GRASP-like saving algorithm, after which a variable neighbourhood search algorithm is used to improve the initial solution. A modified version of the well-known transportation problem helps the metaheuristic to quickly assign students to stops.
Genetic algorithm [96]	School bus routing problem	Use the GENROUTER system to route school buses for two school districts. The routes obtained by GENROUTER system were superior to those obtained by the CHOOSE school bus routing system and the current routes in use by the two school districts.
Simulated annealing [97]	Train formation problem	To explore the solution space, where the revised simplex method evaluates, selects, and implements the moves. The neighbourhood structure is based on the pivoting rules of the simplex method that provides an efficient method to reach the neighbours of the current solution.
Genetic algorithm [98]	Train formation problem	The calibration and validation of the GA model are carried out for three different complexity levels of objective functions.
Neural networks [99]	Train formation problem	A training process for neural network development is conducted, followed by a testing process that indicates that the neural network model will probably be both sufficiently fast and accurate, in producing train formation plans.
Column generation based heuristic [54]	Generalized location routing problem with space exploration or generalized location routing problem with profits (GLRPPs)	The problem arises in exploration of planetary bodies where strategies correspond to different technologies. A description of the generalized location routing problem with profits and its mathematical formulation as an integer program are provided. Two solution methodologies to solve the problem—branch-and-price and a three-phase heuristic method combined with a generalized randomized adaptive search procedure—are proposed.
Memetic algorithm [100]	Helicopter routing problem	The personnel transportation within a set of oil platforms by one helicopter that may have to undertake several routes in sequence.
Genetic algorithm [101]	Locomotive routing problem	A cluster-first, the route-second approach is used to inform the multidepot locomotive assignment of a set of single depot problems and after that we solve each problem independently. Each single depot problem is solved heuristically by a hybrid genetic algorithm that in which push forward insertion heuristic (PFIH) is used to determine the initial solution and λ-interchange mechanism is used for neighbourhood search and improving the method.
Genetic algorithm [102]	Locomotive routing problem	The proposed solution approach is tested with real-world data from the Korean railway.
Branch-and-bound method [103]	Locomotive routing problem	Backtracking mechanism that can be added to this heuristic branch-and-price approach.
Heuristic algorithm [50]	Tour planning problem	A heuristic method based on local search ideas.
Heuristic algorithm [104]	Team orienteering problem	Bilevel filter-and-fan method for solving the capacitated team orienteering problem. Given a set of potential customers, each associated with a known profit and a predefined demand, and the objective of the problem is to select the subset of customers as well as to determine the visiting sequence and assignment to vehicle routes such that the total collected profit is maximized and route duration and capacity restrictions are satisfied.
Memetic algorithm [105]	Team orienteering problem	The memetic algorithm is a hybrid genetic algorithm using new algorithms.
Branch-and- price algorithm [106]	Team orienteering problem	Includes branching rules specifically devoted to orienteering problems and adapts acceleration techniques in this context.
Tabu search algorithm [107]	Team orienteering problem	A variable neighbourhood search algorithm turned out to be more efficient and effective for this problem than two Tabu search algorithms.
Ant colony optimization [108]	Team orienteering problem	The sequential, deterministic-concurrent and random-concurrent,and simultaneous methods are proposed to construct candidate solutions in the framework of ACO.
Iterated local search heuristic [109]	Team orienteering problem	An algorithm that solves the team orienteering problem with time windows (TOPTW).
Simulated annealing [110]	Team orienteering problem	Two versions of the proposed SA heuristic are developed and compared with existing approaches.

Table 1: Continued.

Algorithm	Problem	Contribution
GRASP [111]	Team orienteering problem	A greedy randomised adaptive search Procedure for solving the Team orienteering problem.
GLS, VNS, ILS [112]	Tourist trip design problems	Guided local search (GLS) and variable neighbourhood search (VNS) are applied to efficiently solve the TOP. Iterated local search (ILS) is implemented to solve the TOPTW.
Tabu search [113]	Team orienteering problem	The Tabu search heuristic is embedded in an adaptive memory procedure that alternates between small and large neighbourhood stages during the solution improvement phase. Both random and greedy procedures for neighbourhood solution generation are employed and infeasible, as well as feasible, solutions are explored in the process.
Tabu search [114]	Truck and trailer routing problem	A solution construction method and a Tabu search improvement heuristic coupled with the deviation concept found in deterministic annealing is developed.
Simulated annealing [115, 116]	Truck and trailer routing problem	The combination of a two-level solution representation with the use of dummy depots/roots, and the random neighbourhood structure which utilizes three different types of moves.
GRASP [117]	Truck and trailer routing problem	A hybrid meta-heuristic based on GRASP, VNS and path relinking.
Branch-and-cut [118]	Maritime inventory routing problem	A case study of a practical maritime inventory routing problem (MIRP) shows that the proposed neighbour and algorithmic framework are flexible and effective enough to be a choice of model and solution method for practical inventory routing problems.
Branch-and-cut [119]	Inventory routing problem	The algorithms could solve the instances with 45 and 50 customers, 3 periods and 3 vehicles.
Branch-and-cut [120]	Inventory routing problem	The algorithm solves the IRP with several vehicles and with many products, each with a specific demand, but sharing inventory and vehicle capacities.
Branch-and-cut [121]	Inventory routing problem	They implement a branch-and-cut algorithm to solve the model optimally.
Branch-and-price [122]	Inventory routing problem	A new branching strategy to accommodate the unique degeneracy characteristics of the master problem, and a new procedure for handling symmetry. A novel column generation heuristic and a rounding heuristic were also implemented to improve algorithmic efficiency.
Local search [123]	Inventory routing problem	Our model takes into account pickups, time windows, drivers' safety regulations, orders, and many other real-life constraints. This generalization of the vehicle-routing problem was often handled in two stages in the past: inventory first, routing second.
Genetic algorithm [124]	Inventory-distribution problem	The delivery schedule represented in the form of a 2-dimensional matrix and two random neighbourhood search mechanisms are designed.
Genetic algorithm [125]	Bus Terminal Location Problem	A new crossover and mutation for the BTLP.
Branch-and-price method [126]	Maritime inventory routing problem	The method is tested on instances inspired from real-world problems faced by a major energy company.
Variable neighbourhood search [127]	Inventory routing problem	A variable neighbourhood search (VNS) heuristic for solving a multiproduct multiperiod IRP in fuel delivery with multi-compartment homogeneous vehicles, and deterministic consumption that varies with each petrol station and each fuel type.
Branch-and-cut [128]	Airline crew scheduling problems	The branch-and-cut solver generates cutting planes based on the underlying structure of the polytope defined by the convex hull of the feasible integer points and incorporates these cuts into a tree-search algorithm that uses automatic reformulation procedures, heuristics and linear programming technology to assist in the solution.
Simulated annealing [129]	Airline crew scheduling problems	Computational results are reported for some real-world short-to medium-haul test problems with up to 4600 flights per month.
Simulated annealing [130]	Airline crew scheduling problems	The first step uses the "pilot-by-pilot" heuristic algorithm to generate an initial feasible solution. The second step uses the Simulated Annealing technique for multi-objective optimization problems to improve the solution obtained in the first step.

Table 1: Continued.

Algorithm	Problem	Contribution
Genetic algorithms [131]	Airline crew scheduling problems	The development and application of a hybrid genetic algorithm to airline crew scheduling problems. The hybrid algorithm consists of a steady-state genetic algorithm and a local search heuristic. The hybrid algorithm was tested on a set of 40 real-world problems.
Simulated annealing [132]	Train scheduling problem	They integrated the train routing the train routing problem and the train scheduling problem. They used simulated annealing to solve the problem. The objective is to minimize operational costs (fuel, crew, capital, and freight car rental costs) without missing cars.
Genetic algorithm [133]	Train scheduling problem	They applied GA for solving the freight train scheduling problem in a single track railway system.
Genetic algorithm [134]	Train scheduling problem	They solved the passenger train scheduling problem by attempting to minimize the waiting time for passengers changing trains. They proposed a GA with a greedy algorithm to obtain the sub-optimal solutions.
Genetic algorithm [135]	Train dispatching problem	A model for train dispatching on lines with double tracks. The model can optimize train dispatching by adjusting the order and times of train departures from stations, and then the efficiency of the method is demonstrated by simulation of the Guangzhou to Shenzhen high-speed railway.
Genetic algorithm [136]	Train timetable problem	To obtain the optimal train timetables to minimize delay and changes of gates, they divided the railway network into multiple block, used the branch-and-bound method to determine the train sequence for each block, and calculate the train times. They applied GA to improve the solutions.
ACO [137]	Railroad blocking problem	An ant colony optimization algorithm for solving RBP. The solution method is applied to build a car blocking plan in the Islamic Republic of Iran Railways.
Very large-scale neighbourhood [71]	Railroad blocking problem	An algorithm using a technique known as very large-scale neighbourhood (VLSN) search that is able to solve the problem to near optimality using one to two hours of computer time on a standard workstation computer.
ACO [138]	Railroad blocking problem	A new formulation for RBP in coal heavy haul rail network in north China. An improved ACO to solve a new formulation for RBP in coal heavy haul rail network in north China. They discussed the problem with direct train routing and frequencies and they did not consider the terminal capacity in handling classification process and maximum available blocks constraints.
Multiobjective evolutionary algorithms [139]	Aeronautical and aerospace design problems	A taxonomy and a comprehensive review of applications of MOEAs in aeronautical and aerospace design problems. They provide a set of general guidelines for using and designing MOEAs for aeronautical and aerospace engineering problems.
Genetic algorithms [140]	Aerospace problems	The paper uses GA to solve H-2 and H-infinity norm model reduction problems and helps obtain globally optimized nominal models.
Genetic algorithms [44]	Military transport planning (MTP)	They study a logistics problem arising in military transport planning. A Niche genetic algorithm, together with a hybridized variant, is applied to the problem.
GRASP [141]	School bus routing problem	A matheuristic that uses a GRASP construction phase followed by a variable neighbourhood descent (VND) improvement phase to solve 112 instances with 5 stops and 25 students to 80 stops and 800 students of the SBRP.
ACO [142]	School bus routing problem	A hybrid evolutionary computation based on an artificial ant colony with a variable neighbourhood local search algorithm to solve the urban bus routing problem in the Tunisian case.
Hybrid algorithm [143]	School bus routing problem	A mixed load improvement algorithm to solve 48 test instances for the SBRP with a number of schools 6, 12, 25, 50, and 100 and bus stops 250, 500, 1000, and 2000.
Tabu search [144]	School bus routing problem	In addition to the min-max vehicle routing problem criterion imposed on the time it takes to complete the longest route, school districts are concerned with the minimization of the total distance travelled and they develop a solution procedure for this problem by applying Tabu search within the framework of Multiobjective Adaptive Memory Programming and compare it to an implementation of the Non-dominated Sorting Genetic Algorithm— a well-known approach to multiobjective optimization.

Table 1: Continued.

Algorithm	Problem	Contribution
Hybrid algorithm [145]	School Bus Routing Problem	For a school bus routing problem, called the MV-TPP-RC, which combines a bus stop selection and bus route generation with additional constraints on certain resources, we have developed a BCP algorithm as an implementation of a set partitioning formulation proposed for that problem. This formulation has been obtained from a Dantzig-Wolfe decomposition of a three-index variables model that describes the MV-TPP-RC.

from outside the system to node j; and $E_{j,\text{output}}$ is the energy from node j to outside the system (electric demand).

3.7. Intermodal Transportation Problems. The Intermodal Transportation Problems using more than one transportation mode are as follows. The main variants of the Intermodal Transportation Problems are intermodal multicommodity routing problem with scheduled services [67], tour planning problem (TPP) [50], tourist trip design problems [68], railroad blocking problem (RBP) [69], and intertemporal demand for international tourist air travel [70].

The railroad blocking problem (RBP) is a multicommodity-flow, network-design, and routing problem [71], and RBP is the railroad blocking problem which is one of the most important decisions in freight railroads. The mathematical model of RBP [69] is formed by (53)–(59):

$$\text{Min } z = \sum_{k\in K}\sum_{a\in A} c_a v_k x_a^k, \tag{53}$$

$$\sum_{\substack{a\in A\\ \text{orig}(a)=i}} x_a^k - \sum_{\substack{a\in A\\ \text{dest}(a)=i}} x_a^k = \begin{cases} 1, & \text{orig}(a) = i,\\ -1, & \text{dest}(a) = i,\\ 0, & \text{otherwise,}\end{cases} \quad \forall i \in N, k \in K, \tag{54}$$

$$\sum_{k\in K} v_k x_a^k \le u_a y_a, \quad \forall a \in A, \tag{55}$$

$$\sum_{\substack{a\in A\\ \text{orig}(a)=i}} y_a \le B(i), \quad \forall i \in N, \tag{56}$$

$$\sum_{k\in K}\sum_{\substack{a\in A\\ \text{orig}(a)=i}} v_k x_a^k \le V(i), \quad \forall i \in N, \tag{57}$$

$$y_a \in \{0,1\}, \quad \forall a \in A, \tag{58}$$

$$x_a^k \in \{0,1\}, \quad \forall a \in A,\ \forall k \in K, \tag{59}$$

where $G = (N, A)$ is the graph with terminal set N and potential blocks set A, K is the set of all commodities k designated by an origin-destination pair of nodes, v_k is the volume of commodity k, orig(k) is the origin terminal for commodity k, dest(k) is the destination terminal for commodity k, orig(a) is the origin of potential block a, dest(a) is the destination of potential block a, u_a is the capacity of potential block a, c_a is the per unit cost of flow on arc a (assumed equal for all commodities), $B(i)$ is the number of blocks which may originate at terminal I, and $V(i)$ is the volume which may be classified at terminal i, $x_k = 1$, if commodity k is flowing on block a, 0 otherwise. $Y_a = 1$ if block a is included in the blocking network, 0 otherwise.

The objective of the railroad blocking problem (RBP) is to minimize the sum of the costs of delivering each commodity using the blocking network formed by blocks for which $y_a = 1$ (53). In (54), for each terminal there are balance equations for the flow of each commodity. For each potential block, equations in (55) prevent flow on blocks which are not built and enforce the upper bound u_a on flow for blocks which are built. The constraints (56) enforce the terminal limit $B(i)$ for the sum of the blocks which leave the terminal. The constraints (57), (58), and (59) model the volume of cars, which may be classified at each terminal.

4. Algorithms to Solve Transportation Problems

Various algorithms to solve the Transportation Problems (Table 1) may be found in the literature. We mention only some of the most popular algorithms to solve the Transportation Problems.

5. Conclusions

The paper survey mathematical models and algorithms used to solve different types of transportation modes by air, water, space, cables, tubes, and road. It presents the variants, classification, and the general parameters of the Transportation Problems.

As future work, we propose to investigate mathematical models of the space transportation problems, maritime transportation issues, and the creation of new algorithms that solve these problems.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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