طراحی شبکه در سیستم های حمل و نقل:

سیستمهای حمل ونقل چندوجهی (ترکیبی)
Multimodal Transportation Systems

دانشگاه کردستان

دکتر قادری

Intermodal Transportation Systems

Ref:

[1] Crainic, T.G. and Kim, K.W. (2007) “Intermodal Transportation in Handbook in Operations Research & Management Science (eds) C. Barnhart and G. Laporte, pages 467-477.

[2] Macharis, C. and Bontekoning, Y.M. (2004) “Opportunities for OR in intermodal freight transport research: A review”, *European Journal of Operational Research*, 153, 400-416.

[3] SteadieSeifi, M., Dellaert, N.P., Nuijten, W., Woensel, T. Van and Raoufi, R. (2013) “Multimodal freight transportation planning: A literature review”, *European Journal of Operational Research*

تعاریف و مفاهیم اولیه

حمل و نقل ترکیبی (چندوجهی): Multimodal Transportation System

منظور از حمل و نقل ترکیبی (چندوجهی) انتقال کالا از مکانی به مکان دیگر(کشوری به کشور دیگر)، حداقل با دو شیوه حمل و تحت قرارداد و مسئولیت واحد مربوطه می باشد و همین مسئولیت، این نوع حمل را از حمل مجزا Uni-Modal و چندشیوه ای InterModal متمایز می سازد.

شخصی که خود یا نماینده اش با انعقاد قرارداد حمل چندوجهی، مسئولیت حمل در تمام مسیر را می پذیرد، متصدی حمل و نقل چندوجهی نامیده می شود و ممکن است یک شخص حقیقی یا حقوقی باشد.

- Multimodal transportation offers an advanced platform for more efficient, reliable, flexible, and sustainable freight transportation.

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تعاریف و مفاهیم اولیه

(واژگان مشابه در حمل و نقل چندوجهی)(Ref. [3])

- Multimodal transportation: Multimodal freight transportation is defined as the transportation of goods by a sequence of at least two different modes of transportation. The unit of transportation can be a box, a container, a swap body, a road/rail vehicle, or a vessel. As such, the *regular and express delivery system on a regional or national scale*, and *long-distance pickup and delivery services* are also examples of multimodal transportation.
- Intermodal transportation: (Focuses on the same loading unit and different responsibilities) Intermodal freight transportation is defined as a particular type of multimodal transportation where the load is transported from an origin to a destination in one and the same intermodal transportation unit (e.g. *a TEU (Twenty foot Equivalent Unit) container*) without handling of the goods themselves when changing modes. Intermodal terminals around the globe give companies the flexibility and the economies of scale of using multiple modes.
- Co-modal transportation: emphasizes on the recourse utilization
- Synchromodal transportation: emphasizes on the flexibility aspect

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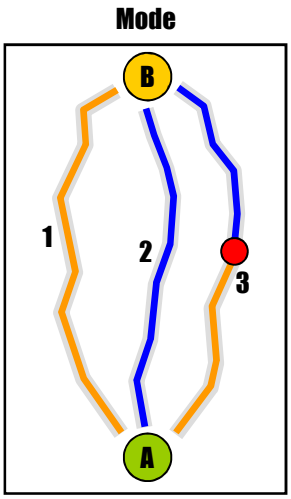
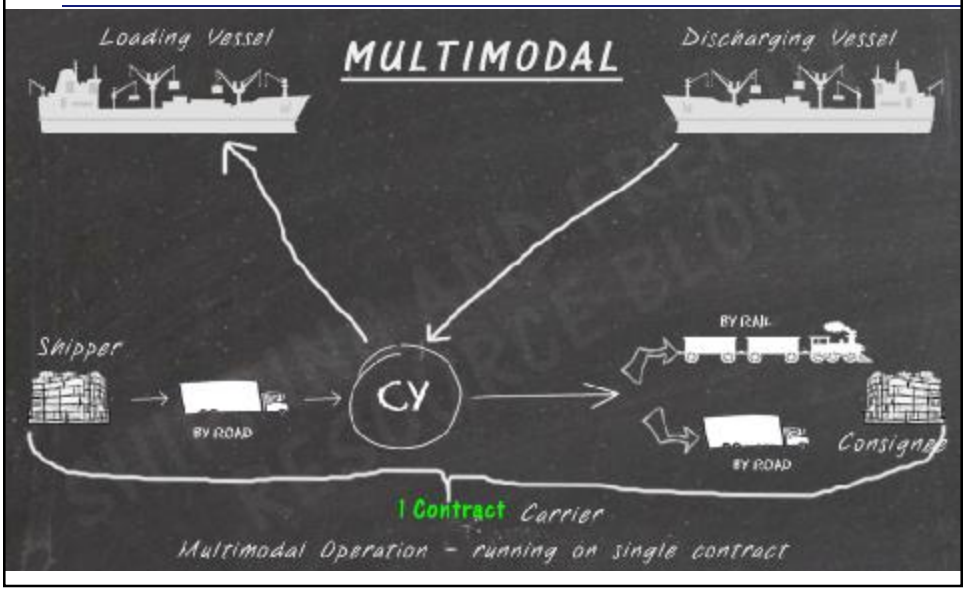
Transport options: …-modals

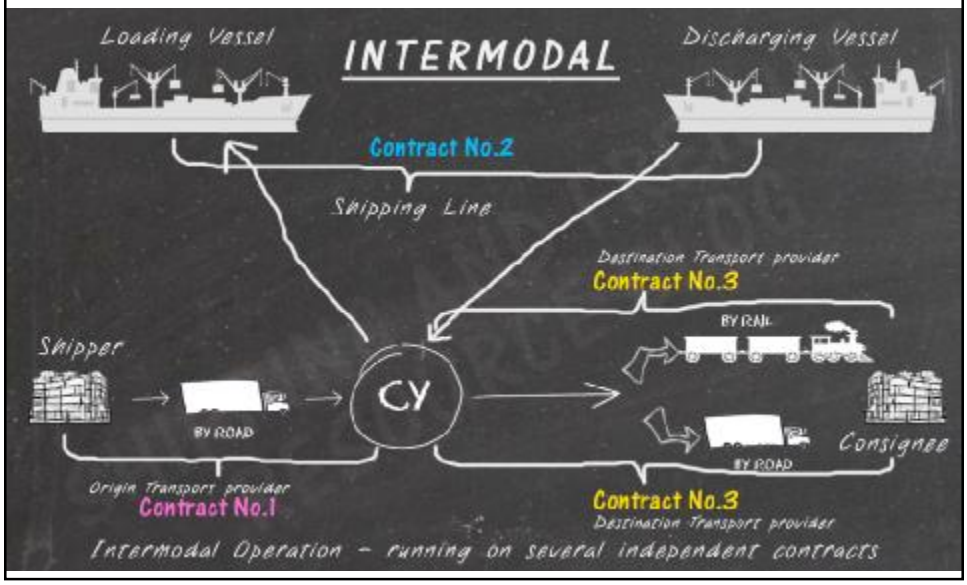
- Transport of goods by several modes.
  - One of the carriers organizes the whole transport from point of origin to destination.
  - If he takes responsibility only for the portion he performs himself, he may issue an ***inter-modal*** or ***combined transport*** bill of loading.
  - If he takes responsibility for the entire transport, he issues an ***Multi-modal transport*** *document.*



Multimodal Transportation System



Intermodal Transportation System

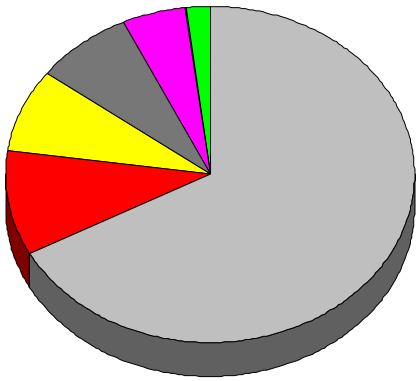


Commercial significance of multimodal transport

1. **What is multimodal transport?**
   - No single authoritative definition
   - carriage by two or more modes of transport
   - door-to-door transport
   - one contract with one party assuming responsibility throughout
   - one document
   - terms also used: intermodal transport, combined transport
2. **Growth in world containerized trade**

Intermodal Share of US Transport Market

2010 US Shipments	(TONS)	
Truck	12,490	68%
Rail	1,776	10%
Pipeline	1,494	8%
Intermodal	1,380	8%
Water	860	5%
Air	12	0%
Other	302	2%
Total	18,313	



Intermodal: transportation of freight in an multi-mode container (rail, ship, or truck) without handling the freight when changing modes.

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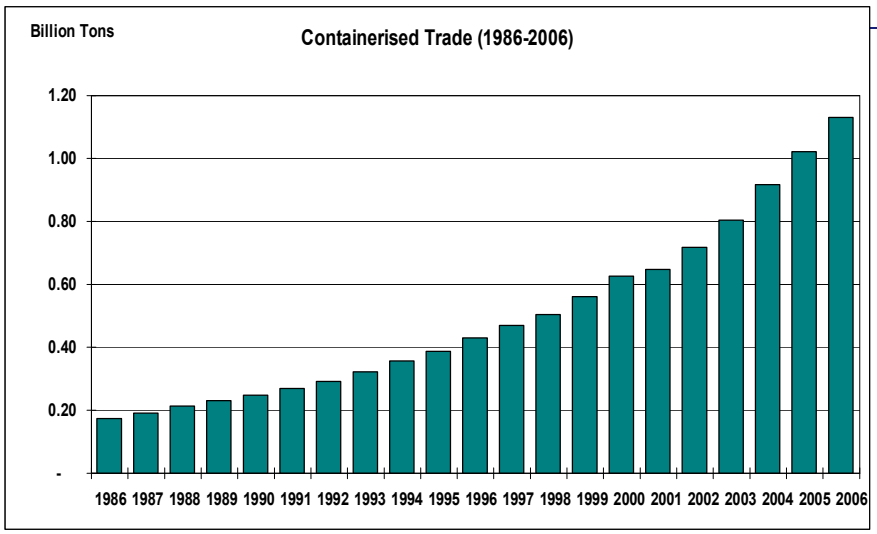
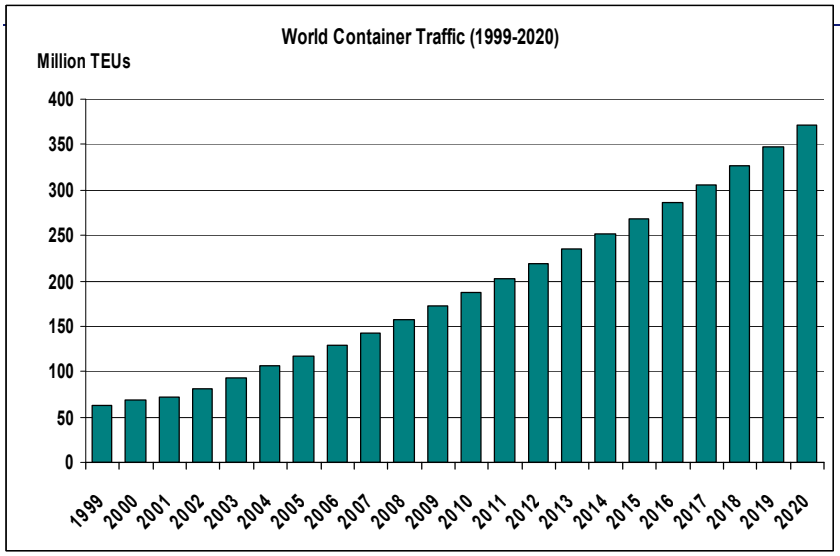
Growth in World Containerised Trade



Source: Clarkson Research Services, Shipping Review Database, Spring 2007, Page 101.

Containerised Trade: Forecast



Source: Drewry Shipping Consultant

Intermodal Transportation

- **Includes more than one mode**
  - **air, rail, road, water**
  - **only truck is only practical single mode trip**
- **Typically refers to containerized goods**
  - **as opposed to bulk (grain, bananas, coffee beans) or general cargo**
  - **requires containers**
  - **less labor than traditional freight handling**
- **The majority of the costs are incurred between modes (in terminals)**

یکپارچه سازی از طریق چندوجهی شدن

Integration through Inter-modalism

- **Conventional:**

  Competition between the modes. Transport system segmented and un-integrated. Each mode to exploit its own advantages in terms of cost, service, reliability and safety.

- **Intermodalism:**

  Involving the use of at least two different modes. The line-haul economies of rail may be exploited for long distances, with the efficiencies of trucks providing local pick up and delivery.

  The key is that the entire trip is seen as a whole, rather than as a series of legs.

What an Multi-modal Transport Operator looks for

- **Minimising cost.**
- **Minimum handling.**
- **Standard procedures and minimum documentation**
- **Hassle-free border crossing with minimum detention.**
- **Security of Cargo**

Containerisation ensures much of these.

تعاریف و مفاهیم اولیه

- سه بخش اصلی زنجیره حمل و نقل:

- A transportation chain is basically partitioned in three segments:
  1) pre-haul (or first mile for the pickup process)
  2) long-haul (door-to-door transit of containers)
  3) end-haul (or last mile for the delivery process).
- In most cases, the pre-haul and end-haul transportation is carried out via road, but for the long-haul transportation, road, rail, air and water modes can be considered.

- تمرکز اصلی حمل و نقل چند وجهی بر حمل و نقل کانتینری است:

- Key reasons for containerization are an **increase in the safety of cargo**, **reduction of handling costs**, **standardization**, and **accessibility to multiple modes of transportation**.

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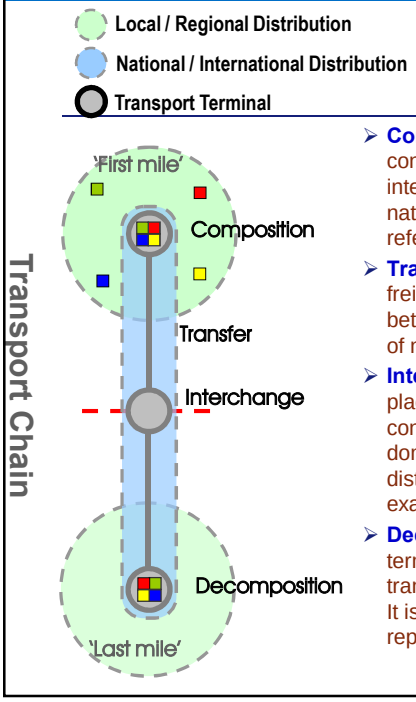
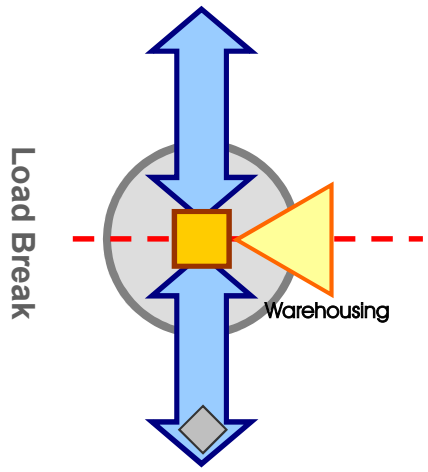
زنجیره حمل و نقل شامل موارد زیر است:

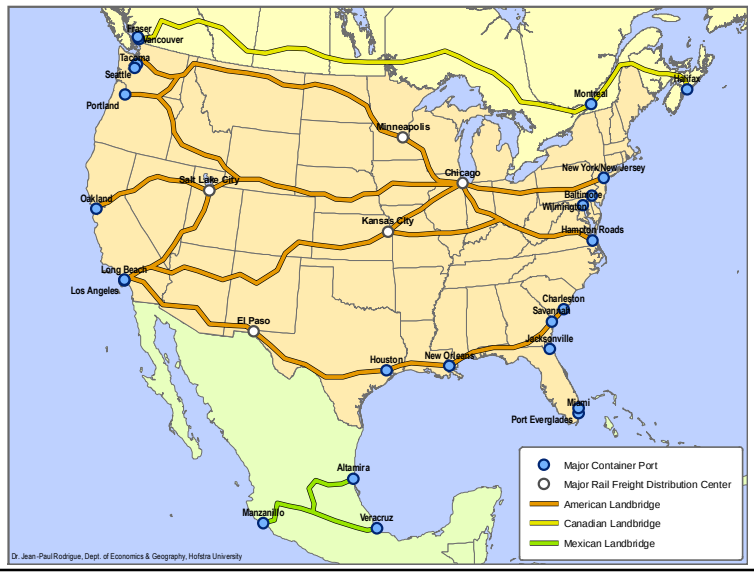


- **Composition** is the process of assembling and consolidating freight at a terminal that offers an intermodal interface between a local / regional distribution system and a national / international distribution system. It is commonly referred as the 'first mile'.
- **Transfer** involves a consolidated modal flow, such as a freight train or a containership (or even fleets of trucks), between at least two terminals, which happens on the realm of national or international freight distribution systems.
- **Interchange** concerns the major intermodal function taking place at terminals whose purpose is to provide an efficient continuity within a transport chain. Those terminals are dominantly within the realm of national or international freight distribution systems, with ports being the most notable example.
- **Decomposition**. Once a load of freight has reached a terminal close to its destination it has to be fragmented and transferred to the local / regional freight distribution system. It is commonly referred as the 'last mile' and often represents one of the most difficult segment of distribution.

گره های انتقال (ترمینال ها) در شبکه

The Transshipment Node (interchanges)





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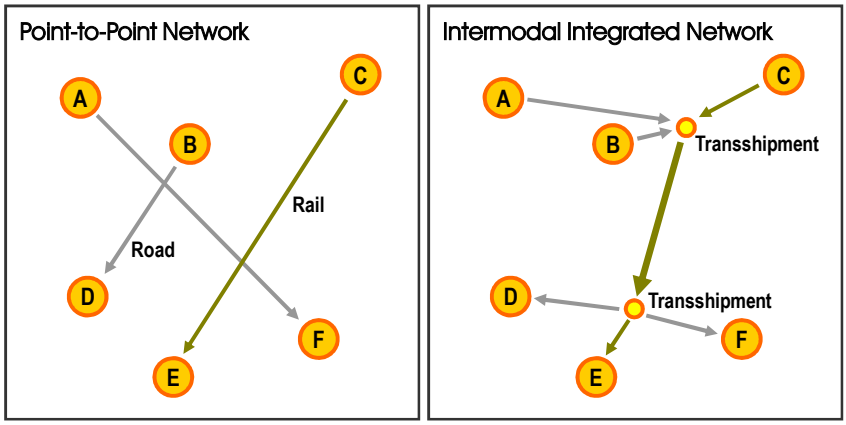
Intermodal Transportation



مسائل برنامه ریزی استراتژیک در حمل ونقل چندوجهی (Ref. [3])

- Strategic planning problems relate to ***investment decisions*** on the present infrastructures (networks).
- In order to ***maximize the utilization of multimodal transportation***, ***consolidation*** is essential. In a consolidation system, instead of direct shipment of every cargo, low volume cargo is moved to a consolidation center and bundled into larger flows, transported by high-frequency and high-capacity multimodal services. These services have lower prices, expressed by discount factors per load unit, compared to other links.
- In practice, there are various transportation ***network topologies***: ***direct link***, ***corridor***, ***hub-and-spoke***, ***connected hubs***, ***static routes***, and ***dynamic routes***.

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Transportation network topologies

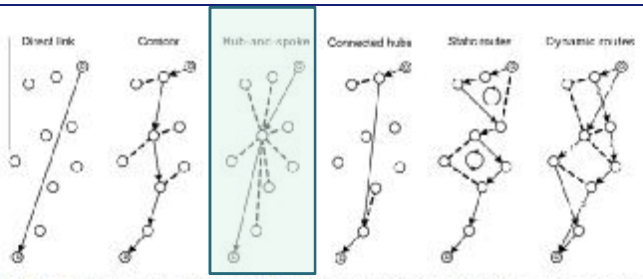

Fig. 2. Six options for O/D transportation in a network of ten nodes. Dotted lines show operationally related links in the network design. In 'Dynamic routes', two alternative routes are shown. In all other designs, the routing is predefined [Woxenius, 2007].

- In the literature, consolidation systems are mostly configured as **hub-and-spoke networks**, with hub being a freight handling (consolidation) facility. Locations of hubs are determined and spoke nodes are allocated to the hubs. These problems are called **hub location problems**.
- A **hub-and-spoke organization** allows a **much higher frequency of service** between all origin–destination pairs in the network and a **more efficient utilization of resources**.

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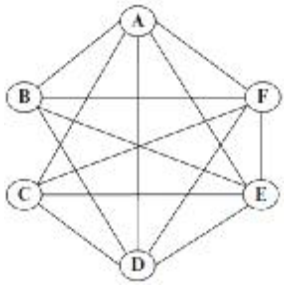
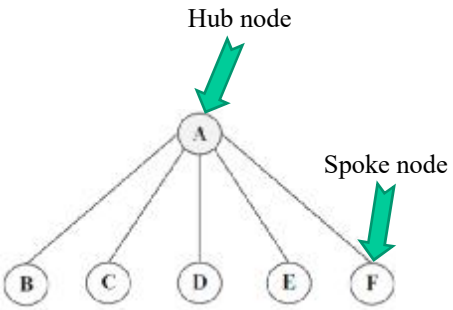
Introduction: what are hub facilities?

- **Hubs are special facilities that serve as switching, transshipment and sorting points in many-to-many distribution systems.**



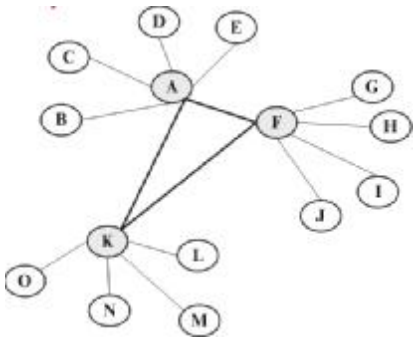
A fully connected network with 6 nodes and 30 origin-destination pairs



A hub and spoke network with 6 nodes and 30 origin-destination pairs

what is hub location problem?

- **Hub location problems involve locating hub facilities and discounted transportation links, allocating origin and destinations nodes (e.g., cities) to hubs, and routing flows through the network.**



what is hub location problem?

In hub location problems :

- **Goal to minimize total cost (as a function of distance) of transportation between hubs, facilities and demands.**
- **Rather than serving every origin-destination demand with a direct link, a hub network provides service via smaller set of links between origin/destinations and hubs, and between pairs of hubs.**
- **Hub network allows large set of origins to be connected with fewer links, via central hub facilities.**
- **Use of fewer links in the network concentrates flows and allows economies of scale to be exploited.**

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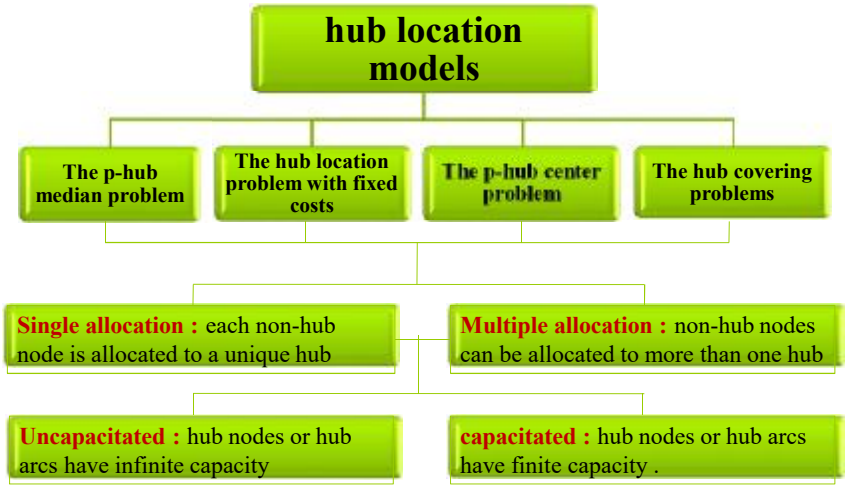
Main hub location models



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طبقه بندی مدل های پایه مکان یابی هاب

- **Hub median:** The main objective of hub median problems is to minimize total transportation cost. If there is a maximum limit on the number of hubs, it is called the p-hub median problem.
- **Hub center problems:** the objective is to minimize maximum distance (cost) between Origin–Destination (O/D) pairs.
- **Hub covering problems:** the objective function is to maximize the total number of served spoke nodes.
- **حوزه ی کاربرد مدل های فوق:**
- Where maximizing market share and customer recognition is the prime goal, hub covering problems offer the best approach to model them.
- In comparison, hub center problems are suitable for designs where immense worst-case O/D distance is not desirable, especially in time-sensitive delivery systems.

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فرضیات مسائل مکان یابی هاب

- The interhub network is a complete graph or not
- The spoke nodes are always interconnected or not
- Direct shipment between spoke pairs is allowed or not (like direct shipment by trucks is commonly used)
- The flow of cargo traverses at most two hubs
- …

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انتخاب مدل مناسب هاب در مسائل حمل و نقل چندمحصولی

- The nature of products plays an important role in choosing the suitable hub location model, particularly in multi-commodity freight transportation.
- The hub median problem is widely used but the hub center problem is usually more suitable for planning huge networks, or planning delivery of perishable or time-sensitive cargos.
- Multi-commodity is critical in the distribution of sensitive cargo such as perishable and hazardous products. In practice, there are some preservation or safety restrictions in consolidating such cargo that affects their flow and might affect the design of the network.

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نحوه ی تخصیص spoke ها به Hubها

- **The single allocation:** flow of spoke nodes can be assigned to only one hub
- **Multi- allocation:** flow of spoke nodes is allowed to be assigned to more than one hub node.
- ***r*- allocation:** spoke nodes are allocated to at most ***r*** hubs.
- **Hierarchical allocation:** the interhub network, connecting only pairs of hubs has two levels. Spoke nodes are allocated to the first level hubs and these hubs are allocated to second level larger hubs.

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The hierarchical hub median network with single assignment

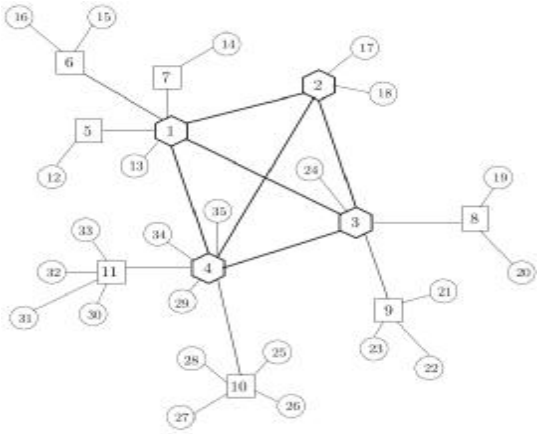

Fig. 1. A three level network on 35 nodes with 11 hubs and 4 central hubs.

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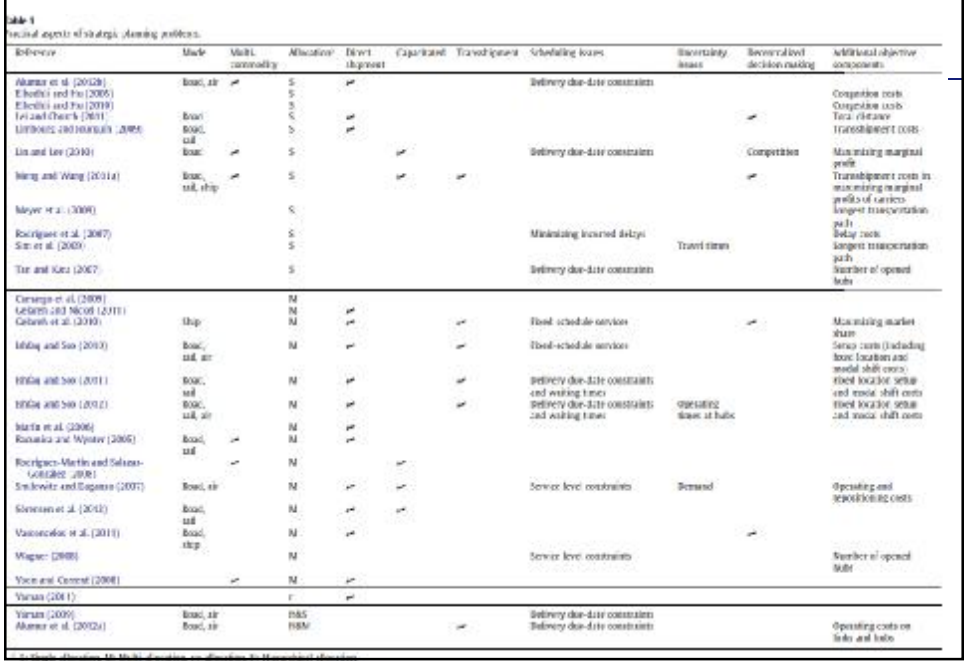
جنبه های عملی مسائل برنامه ریزی استراتژیک (Ref. [3])



مدل سازی مسائل هاب (Ref. [1])

پارامترهای مسئله:

- The formulation proposed by Crainic et al. (1989) is based on a directed Network $G = (N, A)$, where:
  - N is the set of nodes or vertices;
  - A is the set of arcs or links.
- The set of nodes is partitioned into three subsets:
  - O, the set of origin nodes (supply customers);
  - D, the set of destination nodes (demand customers); and
  - H, the set of hubs or consolidation nodes (depots).
- P is the set of commodities
- c_{ij}^{p}: nonnegative cost for each unit of flow of commodity $\boldsymbol{p}$ moving on arc $\boldsymbol{(i\ j)}$.
- d_{ik}^{p} : Quantity of commodity p to be transported from origin terminal i to destination terminal k.

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مدل سازی مسائل هاب

متغیرهای تصمیم

y_j = 1, if a consolidation terminal is located at site j and 0, otherwise;
y_{ij} = 1, if terminal i is linked to hub j and 0, otherwise;
x_{ijlk}^{p}: Flow of commodity p with origin i and destination k that passes through hubs j and l, in that order.

شبکه ی مسئله مورد بررسی

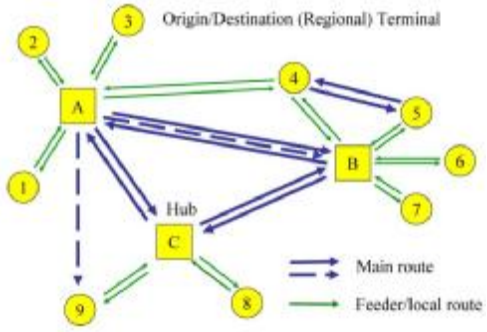

Fig. 1. Network with consolidation terminals/hubs.

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مدل سازی مسائل هاب

فرضیات مدل:

- all traffic passes through two hubs on its route from its origin to its destination,
- no hub capacities,
- no direct transport between nonhub terminals,
- no fixed costs for establishing a link between regional and a consolidation terminal,
- in all hub-based problems, interhub transportation is assumed to be more efficient due to the concentration of flows. Consequently, interhub links are assigned a lower unit cost than links representing the other movements in the system,
- exactly P hubs have to be located out of the |H| potential sites.

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فرمولاسیون مدل p-median hub problem ارائه شده توسط O'Kelly (1987)

The objective function (18) minimizes the total transportation cost of the system

$$\text{minimize} \quad \sum_{p\in\mathcal{P}}\Bigg\{\sum_{i\in\mathcal{O}}\sum_{j\in\mathcal{H}}c_{ij}^{p}y_{ij}\Bigg(\sum_{l\in\mathcal{H}}\sum_{k\in\mathcal{D}}x_{ijlk}^{p}\Bigg) + \sum_{l\in\mathcal{H}}\sum_{k\in\mathcal{D}}c_{lk}^{p}y_{lk}\Bigg(\sum_{i\in\mathcal{O}}\sum_{j\in\mathcal{H}}x_{ijlk}^{p}\Bigg) + \sum_{j\in\mathcal{H}}\sum_{l\in\mathcal{H}}c_{jl}^{p}y_{ij}y_{lk}\Bigg(\sum_{i\in\mathcal{O}}\sum_{k\in\mathcal{D}}x_{ijlk}^{p}\Bigg)\Bigg\} \tag{18}$$

subject to

$$\sum_{j\in\mathcal{H}}y_j = P, \tag{19}$$

$$\sum_{j\in\mathcal{H}}\sum_{l\in\mathcal{H}}x_{ijlk}^{p} = d_{ik}^{p}, \quad i\in\mathcal{O}, k\in\mathcal{D}, p\in\mathcal{P}, \tag{20}$$

$$y_{ij}\leqslant y_j, \quad i\in\mathcal{O}, j\in\mathcal{H}, \tag{21}$$

$$y_{lk}\leqslant y_l, \quad k\in\mathcal{D}, l\in\mathcal{H}, \tag{22}$$

$$x_{ijlk}^{p}\leqslant d_{ik}^{p}y_j, \quad i\in\mathcal{O}, k\in\mathcal{D}, j,l\in\mathcal{H}, p\in\mathcal{P}, \tag{23}$$

$$x_{ijlk}^{p}\leqslant d_{ik}^{p}y_l, \quad i\in\mathcal{O}, k\in\mathcal{D}, j,l\in\mathcal{H}, p\in\mathcal{P}, \tag{24}$$

$$y_j = 0 \text{ or } 1, \quad j\in\mathcal{H}, \tag{25}$$

$$y_{ij} = 0 \text{ or } 1, \quad i\in\mathcal{O}, j\in\mathcal{H}. \tag{26}$$

$$x_{ijlk}^{p}\geqslant 0, \quad i\in\mathcal{O}, k\in\mathcal{D}, j,l\in\mathcal{H}, p\in\mathcal{P}. \tag{27}$$

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فرمولاسیون خطی سازی شده مبتنی بر مسیر Path-based ارائه شده توسط O'Kelly (1987)

$$\text{minimize} \quad \sum_{p\in\mathcal{P}}\sum_{i\in\mathcal{O}}\sum_{j\in\mathcal{H}}\sum_{l\in\mathcal{H}}\sum_{k\in\mathcal{D}}c_{ijlk}^{p}x_{ijlk}^{p} \tag{28}$$

subject to (19), (20), (23)–(25), and (27), where

c_{ijlk}^{p}: Unit cost of transportation for commodity p from origin i to destination k with consolidation at hubs j and l, in that order.

- The two preceding formulations allow multiple allocations of origin and destination terminals to hubs. To **enforce single allocation of terminals** to hubs, constraints (23) and (24) are replaced in the first formulation by:

$$\sum_{j\in\mathcal{H}}y_{ij} = 1, \quad i\in\mathcal{O}, \tag{29}$$

$$\sum_{l\in\mathcal{H}}y_{lk} = 1, \quad k\in\mathcal{D}, \tag{30}$$

$$\frac{x_{ijlk}^{p}}{d_{ik}^{p}} = y_{ij}, \quad i\in\mathcal{O}, k\in\mathcal{D}, j,l\in\mathcal{H}, p\in\mathcal{P}, \tag{31}$$

$$\frac{x_{ijlk}^{p}}{d_{ik}^{p}} = y_{lk}, \quad i\in\mathcal{O}, k\in\mathcal{D}, j,l\in\mathcal{H}, p\in\mathcal{P}. \tag{32}$$

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جلسه آینده:

سیستم های حمل و نقل چندوجهی (ادامه)

Intermodal Transportation System

مسائل برنامه ریزی در حمل ونقل چند وجهی (استراتژیک و تاکتیکال)([1] .Ref)

- در سطح استراتژیک تمرکز بر روی تصمیماتی است که به طراحی شبکه ی فیزیکی زیرساخت مربوطند:
  - ❑ where to locate terminals (e.g., consolidation terminals, rail yards, intermodal platforms, and so on)?
  - ❑ what type and quantity of equipment (e.g., cranes) to install at each facility?
  - ❑ what type of lines or capacity to add?
  - ❑ what lines or facilities to abandon?
  - ❑ which customer zones to serve directly and how to serve the others?
  - ❑ and so on.

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مسائل برنامه ریزی در حمل ونقل چند وجهی (استراتژیک و تاکتیکال)

- در سطح تاکتیکال تهیه یک طرح حمل و نقل (جابه جایی بار) مدنظر بوده به نحویکه منجر به رضایتمندی صاحبان بار (برآورد تقاضا) و استفاده موثر از منابع شده و نهایتاً سودآوری شرکت حمل و نقل را نیز به همراه خواهد داشت:

- on what routes to provide service?
- what type of service (mode) to use?
- how often to offer service on each route and according to what schedule?
- how to route the loads through the physical and service networks?
- how to distribute the work among the terminals of the system?

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مسائل برنامه ریزی تاکتیکال در حمل ونقل چند وجهی

- The physical infrastructure (e.g., the terminal locations) and the available resources are fixed for these problems.
- Service network design problems address the system-wide planning of operations to decide the selection, routing, and scheduling of services, the consolidation activities in terminals, and the routing of freight of each particular demand through the physical and service network of the company.
- The goal is cost-efficient operation together with timely and reliable delivery of demand according to customer specifications and the targets of the carrier.

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مسائل برنامه ریزی تاکتیکال در حمل ونقل چند وجهی (Ref. [3])

- **مسائل برنامه ریزی میان مدت (تاکتیکال) سعی در بهینه سازی موارد زیر دارند:**
  - استفاده از زیرساخت داده شده با انتخاب خدمات و مدهای حمل و نقل مربوطه
  - تخصیص ظرفیت مدهای مختلف به سفارشات
  - برنامه ریزی جهت برنامه ی سفر و حجم مدهای مختلف حمل و نقل
- **تصمیم گیری جهت ارسال بار به صورت مستقیم یا از طریق یک سیستم تلفیقی (یکپارچه، Consolidation) در نتیجه توازن موارد زیر می باشد:**
  - هزینه های سیستم
  - زمان های انجام عملیات یا زمان جابه جایی بار
  - ساختار شبکه در دسترس
  - نیازمندیهای مشتری
- **در ادبیات مسائل برنامه ریزی تاکتیکال، بیشتر از ساختار شبکه hub-and-spoke استفاده می شود.**

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مسائل برنامه ریزی تاکتیکال در حمل ونقل چند وجهی (Ref. [3])

- **Type of services:**
  - Freight on hub-and-spoke networks is transported by ***a single service***, **or** ***a sequence of services*** where the loads are transferred from one service to the next at ***intermediate terminals***.
  - A **service** is characterized by its ***origin***, ***destination***, and ***intermediate terminals***, its ***transportation mode***, ***route***, and its ***service capacity***.
  - A **mode** is characterized by its ***loading capacity***, ***speed***, and ***price***.
  - Usually, these services and modes have ***fixed costs***.

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مسائل برنامه ریزی تاکتیکال در حمل ونقل چند وجهی: مدل های موجود

- **Two groups of models:**
  - **Network Flow Planning (NFP)**, relates to the flow planning decisions addressing ***the movement of orders (commodities) throughout the network***.
  - **Service Network Design(SND)**, involves the service planning decisions including ***all decisions*** on ***choosing*** the ***transportation services and modes to move those commodities***.
    - ❑ The following decisions would be made in **SND**:
      - ✓ the frequency of the service,
      - ✓ the capacity allocation,
      - ✓ the equipment planning, and
      - ✓ the routing and flow of commodities,

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مسائل برنامه ریزی تاکتیکال در حمل ونقل چند وجهی: مدل های موجود

- In both **NFP** and **SND** problems, **continuous variables** are used to represent ***commodity flows*** throughout the network, **but** in SND problems, **binary variables** are included for ***selection of services***.

- **نحوه ی مدل سازی مدل های برنامه ریزی تاکتیکال با توجه به متغیرهای آن:**
  - ❑ The variables can be ***arc-based*** representing flow on an arc or ***path-based*** representing flow on a path (a series of arcs).
  - ❑ SND problems are then modeled as Fixed-Cost Capacitated Multicommodity Network Design (CMND) problems.

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ساختار شبکه و یک جواب در مسئله طراحی شبکه ی چند کالایی

Fig. a Typical Network of Nodes and Links

Fig. b Typical MCNDP solution.

- Different colors depict different commodities that need to travel from an origin to a destination.
- The goal is to select a sub-graph to satisfy this need, as **Fig. b** shows, without violating any capacity constraints at links and while minimizing the total fixed cost of establishing the links and variable cost of traversing the commodities.
- Note that the commodities may be split and follow parallel paths and meet at an intermediate node or at the destination.

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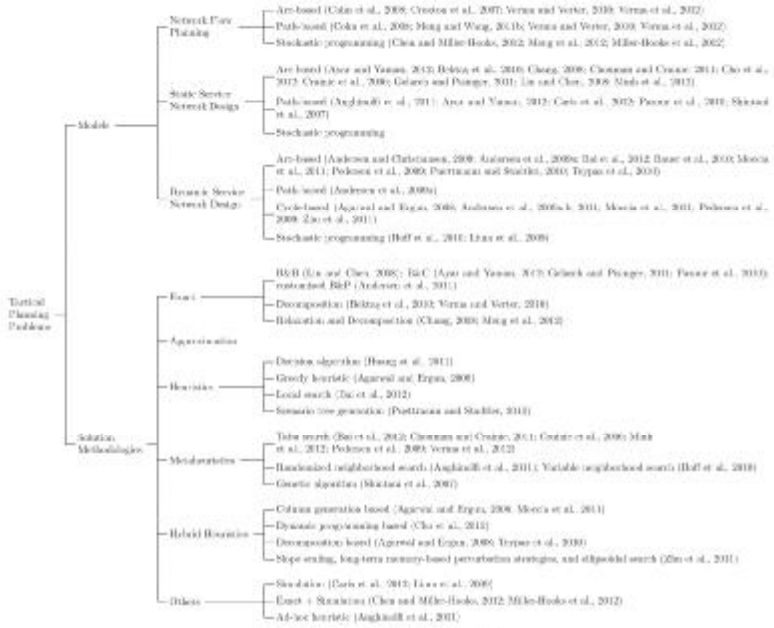

Fig. 3. OR aspects of tactical planning problems.

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Design of postal services (Ref. [1]) بررسی مسئله خدمات پستی

- The design of postal services, regular and those dedicated to express letter and package delivery, yields particularly **large and complex service network design formulations**.
- These applications involve **air** and **land long-haul transportation**, as well as **local pick up and delivery operations**. Land long-haul transportation is often performed by using trucks, although rail is also used in some countries.
- The air mode is both expensive and efficient in carrying relatively large loads over long distances. Due to the high costs, efforts are dedicated to the optimization of available capacity and the reduction of the number of aircrafts used.
- This translates into a relatively large number of alternatives in terms of aircraft types, capacities, and costs which adds to the complexity of the problem.

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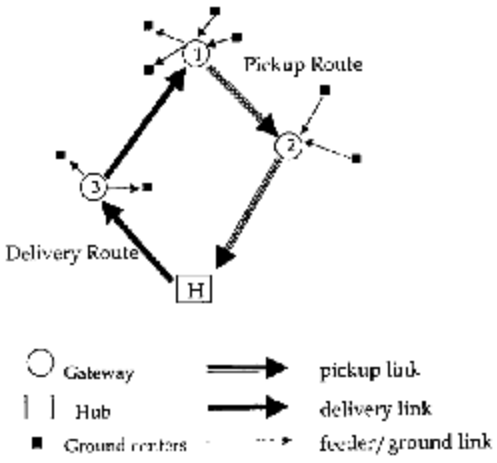
Design of postal services بررسی مسئله خدمات پستی

- ساختار فیزیکی مسئله



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Design of postal services بررسی مسئله خدمات پستی

- شبکه فیزیکی متشکل از موارد زیر است:
  - ✓ مکان دروازه ها (فرودگاه های کوچک، Gateways): نقاطی که محموله ها به شبکه هوایی وارد (یا خارج) می شوند.
  - ✓ مکان هاب ها (فرودگاه های بزرگ): مکانی که محموله ها مرتب و طبقه بندی می شوند.
  - ✓ ناوگان هوایی (aircrafts): انواع مختلفی از ناوگان هوایی
-

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نحوه خدمت رسانی از طریق شبکه ی داده شده:

Consider the network shown in Figure . Packages arrive from customer centers to gateways either on trucks or on small aircraft that service remote locations. When packages enter the air system through a gateway (e.g., node 1), they are loaded onto an aircraft and are transported to a hub (e.g., node II) not later than the hub's *sort start time*. Flying to the hub is done by direct routes or, as in Figure 3-1, via an intermediate gateway (e.g., node 2).

Upon arrival at the hub, packages are unloaded from the aircraft, sorted, and loaded onto aircraft for delivery to their destination gateway. During the sorting process, the inbound planes remain at the hub until they are loaded and ready to start their delivery routes. Hubs may also serve as gateways since packages may either originate or terminate at these locations.

On delivery routes, planes can depart the hub no earlier than the *sort end time*. They deliver packages to the gateway locations, which then sort the packages and send them to ground sorting facilities via truck or feeder aircraft. From there, the packages are delivered to customers.

Design of postal services بررسی مسئله خدمات پستی

- Two types of terminals are considered in the model:
  - **gateways** where packages enter and exit the air network and
  - **hubs** where packages are unloaded from in-coming airplanes, sorted, and loaded into an out-going aircraft for delivery to their destination gateways.
- Aircrafts may fly nonstop between gateways and hubs or stop at one gateway en-route.

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Design of postal services بررسی مسئله خدمات پستی

- سایر اطلاعات و محدودیت های مسئله
- **Time window restrictions** on pickup and delivery times at gateways as well as on the sorting periods at hubs limit the number of stops and constrain the design.
- **Aircrafts of different types** are available in **limited numbers**.
- Each aircraft type has an operating cost and a capacity, as well as operating characteristics (type of engine, flying range, speed, etc.) that determine the routes it can fly.

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Design of postal services بررسی مسئله خدمات پستی

- هدف مسئله
- The **objective** is to design the minimum cost set of routes, aircraft assignments to these routes, and package flows to satisfy demand and level-of-service objectives, while complying with the operating parameters of the terminals (e.g., capacity), aircraft type (e.g., capacity, range, speed), and aircraft fleet (number of planes available).

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Design of postal services

- پارامترهای مسئله:
- $p \in P$: a commodity represents packages to be moved from an origin gateway $o(p)$ to a destination gateway $d(p)$.
- d^p: indicate the corresponding demand,
- H: the set of hubs,
- $\{o(p), d(p), p \in P\}$: the set of origin and destination gateways.
- F: the set of aircraft types available
- R^f: the set of routes (sequence of gateways starting or ending at a hub) that may be flown by aircrafts of type $f \in F$
  - The routes become the flight arcs A linking the hub and gateway nodes N of the system.

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Design of postal services

- پارامترهای مسئله:
- c^f_r: the cost of flying route $r \in R^f$ with aircrafts of type $f \in F$
- u^f_r: gives its capacity.
- n_f: the number of available aircrafts of type f
- a_h: the landing capacity of hub $h \in H$

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Design of postal services

- شاخص ها و متغیرهای مسئله:

Three indicators are also defined: (1) $\delta^{rf}_{ij} = 1$ when flight arc (i, j) is included in route r flown by aircraft type f and 0, otherwise; (2) $\beta^r_i = 1$ (-1) if node i is the origin (destination) gateway of route r and 0, otherwise; and (3) $\delta^h_r = 1$ if hub h is included in route r and 0, otherwise.

Two types of decision variables are defined: y^f_r indicates the number of times route $r \in \mathcal{R}^f$ is flown by aircrafts of type $f \in \mathcal{F}$; continuous variable x^p_{ij} stands for the amount of product p on the air link $(i, j) \in \mathcal{A}$.

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Design of postal services

$$\text{minimize} \quad \sum_{f\in\mathcal{F}}\sum_{r\in\mathcal{R}^f} c_r^f y_r^f \tag{37}$$

subject to

$$\sum_{j\in\mathcal{N}} x_{ij}^p - \sum_{j\in\mathcal{N}} x_{ji}^p = \begin{cases} d^p & \text{if } i = o(p), \\ -d^p & \text{if } i = d(p), \\ 0 & \text{otherwise,} \end{cases} \quad i \in \mathcal{N}, p \in \mathcal{P}, \tag{38}$$

$$\sum_{p\in\mathcal{P}} x_{ij}^p \leqslant \sum_{f\in\mathcal{F}}\sum_{r\in\mathcal{R}^f} \delta_{ij}^{rf} u_r^f y_r^f, \quad (i,j) \in \mathcal{A}, \tag{39}$$

$$\sum_{r\in\mathcal{R}^f} y_r^f \leqslant n_f, \quad f \in \mathcal{F}, \tag{40}$$

$$\sum_{r\in\mathcal{R}^f} \beta_i^r y_r^f = 0, \quad i \in \mathcal{N}, f \in \mathcal{F}, \tag{41}$$

$$\sum_{r\in\mathcal{R}^f} \delta_r^h y_r^f \leqslant a_h, \quad h \in \mathcal{H}, \tag{42}$$

$$y_r^f \geqslant 0 \text{ and integer}, \quad r \in \mathcal{R}^f, f \in \mathcal{F}, \tag{43}$$

$$x_{ij}^p \geqslant 0, \quad (i,j) \in \mathcal{A}, p \in \mathcal{P}. \tag{44}$$

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Design of postal services

$$\text{minimize} \quad \sum_{f\in\mathcal{F}}\sum_{r\in\mathcal{R}^f} c_r^f y_r^f \tag{37}$$

subject to

$$\sum_{j\in\mathcal{N}} x_{ij}^p - \sum_{j\in\mathcal{N}} x_{ji}^p = \begin{cases} d^p & \text{if } i = o(p), \\ -d^p & \text{if } i = d(p), \\ 0 & \text{otherwise,} \end{cases} \quad i \in \mathcal{N}, p \in \mathcal{P}, \tag{38}$$

محدودیت های (38) در ارتباط با تعادل جریان می باشند و نشان می دهند که جریان ورودی کالا بر روی گره های میانی با جریان خروجی برابر بوده و در گره های مبداء و مقصد این مقدار برابر با مقدار تقاضا است.

Design of postal services

$$\text{minimize} \quad \sum_{f\in\mathcal{F}} \sum_{r\in\mathcal{R}^f} c_r^f y_r^f \tag{37}$$

subject to

$$\sum_{j\in\mathcal{N}} x_{ij}^p - \sum_{j\in\mathcal{N}} x_{ji}^p = \begin{cases} d^p & \text{if } i = o(p), \\ -d^p & \text{if } i = d(p), \\ 0 & \text{otherwise,} \end{cases} \quad i \in \mathcal{N}, p \in \mathcal{P}, \tag{38}$$

$$\sum_{p\in\mathcal{P}} x_{ij}^p \leqslant \sum_{f\in\mathcal{F}} \sum_{r\in\mathcal{R}^f} \delta_{ij}^{rf} u_r^f y_r^f, \quad (i,j) \in \mathcal{A}, \tag{39}$$

the forcing constraints (39) restrict the flow on each fly arc to the capacity of the aircrafts flown on that route.

جریان هر یال نبایستی از میزان ظرفیت تخصیص داده شده به آن بیشتر باشد.

Design of postal services

$$\text{minimize} \quad \sum_{f\in\mathcal{F}} \sum_{r\in\mathcal{R}^f} c_r^f y_r^f \tag{37}$$

subject to

$$\sum_{j\in\mathcal{N}} x_{ij}^p - \sum_{j\in\mathcal{N}} x_{ji}^p = \begin{cases} d^p & \text{if } i = o(p), \\ -d^p & \text{if } i = d(p), \\ 0 & \text{otherwise,} \end{cases} \quad i \in \mathcal{N}, p \in \mathcal{P}, \tag{38}$$

$$\sum_{p\in\mathcal{P}} x_{ij}^p \leqslant \sum_{f\in\mathcal{F}} \sum_{r\in\mathcal{R}^f} \delta_{ij}^{rf} u_r^f y_r^f, \quad (i,j) \in \mathcal{A}, \tag{39}$$

$$\sum_{r\in\mathcal{R}^f} y_r^f \leqslant n_f, \quad f \in \mathcal{F}, \tag{40}$$

$$\sum_{r\in\mathcal{R}^f} \beta_i^r y_r^f = 0, \quad i \in \mathcal{N}, f \in \mathcal{F}, \tag{41}$$

$$\sum_{r\in\mathcal{R}^f} \delta_r^h y_r^f \leqslant a_h, \quad h \in \mathcal{H}, \tag{42}$$

Constraints (40) and (42) enforce the number of available aircrafts of each type and the landing capacities at hubs, respectively.

Design of postal services

$$\text{minimize} \quad \sum_{f\in\mathcal{F}}\sum_{r\in\mathcal{R}^f} c_r^f y_r^f \tag{37}$$

subject to

$$\sum_{j\in\mathcal{N}} x_{ij}^p - \sum_{j\in\mathcal{N}} x_{ji}^p = \begin{cases} d^p & \text{if } i = o(p), \\ -d^p & \text{if } i = d(p), \\ 0 & \text{otherwise,} \end{cases} \quad i \in \mathcal{N}, p \in \mathcal{P}, \tag{38}$$

$$\sum_{p\in\mathcal{P}} x_{ij}^p \leqslant \sum_{f\in\mathcal{F}}\sum_{r\in\mathcal{R}^f} \delta_{ij}^{rf} u_r^f y_r^f, \quad (i,j) \in \mathcal{A}, \tag{39}$$

$$\sum_{r\in\mathcal{R}^f} y_r^f \leqslant n_f, \quad f \in \mathcal{F}, \tag{40}$$

$$\sum_{r\in\mathcal{R}^f} \beta_i^r y_r^f = 0, \quad i \in \mathcal{N}, f \in \mathcal{F}, \tag{41}$$

Con.(41) are the **path-based form** of the *aircraft balance restrictions*: the number of aircrafts of each given type landing at a location (delivery routes) must equal the number taking off from that same location (pick up routes).

Design of postal services

$$\text{minimize} \quad \sum_{f\in\mathcal{F}}\sum_{r\in\mathcal{R}^f} c_r^f y_r^f \tag{37}$$

subject to

$$\sum_{j\in\mathcal{N}} x_{ij}^p - \sum_{j\in\mathcal{N}} x_{ji}^p = \begin{cases} d^p & \text{if } i = o(p), \\ -d^p & \text{if } i = d(p), \\ 0 & \text{otherwise,} \end{cases} \quad i \in \mathcal{N}, p \in \mathcal{P}, \tag{38}$$

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$$\sum_{r\in\mathcal{R}^f} \delta_r^h y_r^f \leqslant a_h, \quad h \in \mathcal{H}, \tag{42}$$

$$y_r^f \geqslant 0 \text{ and integer}, \quad r \in \mathcal{R}^f, f \in \mathcal{F}, \tag{43}$$

$$x_{ij}^p \geqslant 0, \quad (i,j) \in \mathcal{A}, p \in \mathcal{P}. \tag{44}$$

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