Dynamic Systems in the Ocean Container Industry: Status & Perspectives

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Central objective, philosophy, & scope

- Present the state-of-the-art of Dynamic Systems (DS) and Dynamic Models (DM) utilized in OCI Operational Research (OR).

- The philosophy of the presentation is to put emphasis on the application side rather than on the theoretical aspects of DS and DM.
- The OCI refers to ocean container carriers and seaport terminals and not to the land transportation of containers.
- Here, we focus on managerial and techno-economic decision problems in the OCI rather than on pure technical aspects.

Literature review

- We state that we are not aware of any other publication reviewing dynamic techniques in the OCI.

- Actually and beyond the OCI, we are not knowledgeable of any publication researching DSs in OCI’s superset, maritime transportation.

Outline

1. Introduction to the OCI and to DS-DM
2. Planning problems & decision-making in the OCI
3. Status of DS and DM in OCI OR
    1. Ocean container carriers' applications
    2. Applications in Container terminals
4. Perspectives of DS and DM in OCI OR
    1. Technological advances
    2. Dynamic liner vessel routing
    3. Dynamic vs. static solutions and problems
    4. System dynamics
5. Conclusions and directions for further research

Introduction to DS and DM

“The DS notion is a mathematical formalization for any fixed ‘rule’ which describes the time dependence of a point's position in its ambient space.”

Wikipedia (2007)

“The term [DS] is also used to refer to mathematical models that evolve in time.”

American Meteorological Society (2000)

“A DM is a model in which the decision variables *do* involve sequences of decisions over multiple periods.”

Winston (2004)

In this presentation, we review both DS & DM and sometimes we use the these terms interchangeably.

Introduction to the OCI: A thriving sector

- Cargo carrying capacity of the world fleet increased 25% over the 1980-2003 period. During the same period the capacity of containerships has increased **727**%.

- Indeed, the containerships tonnage on order is ca. half the current containerships fleet tonnage, whereas this ratio historically has been about 30%.

- World container port throughput for 2002 reached 266.3 million TEUs, an increase of 22.5 million TEUs, or 9.2%, over 2001.

OCI (2)

- “Liner Shipping”

- Cartelized (conference system)
- Market concentration (top-10 carriers control >60%)
- Mainly unitized
- Fixed schedule
- Relatively high value
- Relatively high speed
- Containers
- Ship partly full
- Intermodal issues important

OCI (3)

- Containers' gates to the hinterland are the water container terminals; so, it has evolved interdependence –with its inherent tensions and partnerships- between ocean container carriers and water container terminals.

- Actually, certain ocean carriers' subsidiaries have entered the terminals' business through acquisitions.

- Whereas carriers' core business is the dispatching of containers, the terminals are involved in a plethora of container handling operations such as loading/unloading, storage, and link with other modalities, among others.

Planning Problems in the OCI

- In such a relatively recent (container shipping has a presence of ca. 50 years as opposed to the thousands of years of shipping history), rapidly evolving, and currently prosperous business, real decision/planning problems abound.
- A plethora of managerial problems can be met in both carriers' and terminals' management in all planning levels (strategic, tactical, and operational).
- Essentially, carriers and terminals aim to optimally manage their resources.
- Containerships and port resources are capital investments of tens of millions dollars and the daily operating costs are thousands of dollars.

Planning Problems in the OCI (2)

Table 1. Planning problems in the OCI

Time horizon/ stakeholder	Ocean container carrier	Sea port terminal
Strategic	• Ship design • Market & trade selection • Liner network design • Fleet size & mix • Capacity contract evaluation • Transportation services pricing	• Port location • Port size • Port strategic design • Port services pricing
Tactical	• Fleet size & mix modifications • Fleet deployment • Distribution of empty containers	• Container yard management • Berth allocation • Crane scheduling
Operational	• Containership management • Containership loading/stowage planning • Service speed selection • Environmental routing • Cargo booking	• Stowage sequencing • Automated Guided Vehicles Routing • Yard trailer routing

Decision-making in the maritime industry

- Decision-makers in the maritime industry are often traditionally educated and it is a common phenomenon that senior managers have past extensive on-board experience.

- These planners resolve these problems based on logic, experience, intuition, and sometimes using Microsoft Excel (formerly via pencil-and-paper methods).

- In fact, these planners do a very good job.

- An academic exemplified the shipping companies' outlook on external consultancies as well as with Research & Development (R&D) bodies as follows.
  - "When the industry goes well, the ship-owners think that they do not need the assistance of external consultancies and R&D inasmuch as they manage to profit anyway. On the other hand, when the industry is depressed, they set aside consultancies and R&D, because they are unwilling to bear additional expenses."

- On the whole, maritime planners are skeptical of sophisticated IT systems, decision support systems and of *OR*/*MS* techniques.

Decision-making in the Ocean Container Carriers

As a result of significant and increasing market concentration, the business conditions are relatively favorable for advanced quantitative *MS* techniques.

Unfortunately, their implementation is thwarted by liner carriers' sensitivity to confidentiality.

Consequently, they solve these problems internally (usually via common sense, experience and Microsoft Excel) and do not disclose their methods or insights.

Again, due to confidentiality they rarely approach external consultancies and R&D bodies.

However, liner companies are willing to invest in Information and Telecommunications Systems.

The last is considered significant as it could catalyze in the future the use of optimization-based decision-support systems.

Decision-making in seaport container terminals

- The members of the board engage with strategic, institutional, and competition issues, rather than everyday problems.

- In order to support their operations, ports use computer-based IT systems purchased from companies that specialize in the development of these systems.

- Port planners of major ports are aware of the powerful capabilities of optimization and try to incorporate it into their methodological arsenal to improve their large-scale operations.

Status of DS & DM in carriers planning

Table 2. Summary of literature on dynamic problems related to ship and fleet planning in the OCI.

Paper	Major decision	Comments
Abrache et al (1999)	DECP	Method: decomposition approach
Azaron and Kianfar (2003)	Environmental routing	Method: stochastic dynamic programming; Objective: minimum time.
Barber et al (1994)	Voyage management and weather routing	Method: parallel dynamic programming
Cheung and Chen (1998).	DECP	Formulated as a two-stage stochastic network model.
Crainic et al (1993)	DECP	Formulated as a "large, dynamic, linear, multicommodity, minimum cost, generalized network flow model"; characterized as a two-stage problem
Merrick et al (2001)	Risk management	Method: Simulation and expert judgment
Powell and Carvalho (1998a)	Flow of containers and flatcars	Method: Logistics Queuing Network
Powell and Carvalho (1998b)	Fleet management	Method: Logistics Queuing Network
Powell et al (1995)	Fleet management	Method: Logistics Queuing Network
Psaraftis (1988)	Scheduling	Objective: meet goals; method: heuristics
White (1972)	DECP	Early DECP reference at a time-dependent network
Xie et al (2000)	FS&MP	Objective: minimize costs; method: linear and dynamic programming

Status of DS & DM in terminals planning

Table 3. Summary of literature on dynamic problems related to container terminals

Paper	Major decision	Comments
Alessandri et al (2004)	CYMP	Objective: minimize container transfer delays; formulated as an optimal control problem; solution is sought by adopting a receding-horizon strategy.
Alessandri et al (2007)	CYMP	Same as in Alessandri et al (2004)
Boile et al (2005)	Empty container accumulation problem	Provide descriptive evidence that the problem is dynamic
Bruno et al (2000)	Dynamic AGV positioning	Formulated as a location-allocation problem; method: two heuristics
Chan (2001)	AGV deployment	
Cordeau et al (2005)	Static and dynamic BAP	Overview paper
Corry and Kozan (2006)	Container trains loading	Formulated as a dynamic assignment problem
Daganzo (1989)	Static and dynamic CRSP	Objective: minimize aggregate cost of delay; method: exact and approximation techniques
Dai et al (2004)	Static and dynamic BAP	Formulation: rectangle packing problem with release time constraints; method: local search
Escriva et al (2005)	Data visualization	Method: modular system and 3-D graphics
Grunow et al (2006)	On-line and off-line AGV routing	Method: on-line dispatching strategy adopted from flexible manufacturing systems and pattern-based off-line heuristic.
Guenther et al (2005)	On-line and off-line AGV routing	As in Grunow et al (2006)
Imai et al (2001)	DBAP	Method: Lagrangean relaxation with an assignment subproblem

Status of DS & DM in terminals planning (2)

Table 3. Summary of literature on dynamic problems related to container terminals

Paper	Major decision	Comments
Jula et al (2005)	Empty container reuse	Use of multi-period models
Kim and Park (1998)	Export containers in a container yard	Dynamic space allocation method
Kim and Park (2002)	Export containers in a container yard	Dynamic space allocation method
Kim et al (2000)	Export containers in a container yard	Dynamic space allocation method; objective: minimize container reshuffling
Leong (2001)	AGV deployment	Simulation
Lin (2001).	CRSP	
Linn and Zhang (2003)	CRSP	Method: heuristics
Moccia (2004)	BAP, CRSP, Generalized quadratic assignment problem, service allocation problem	Extensive analysis of the respective problems. Dynamic elements are discussed.

Status of DS & DM in terminals planning (3)

Table 3. Summary of literature on dynamic problems related to container terminals

Paper	Major decision	Comments
Nishimura and Imai (2000)	Container Yard Trailer Routing	
Nishimura et al (2001)	Container Yard Trailer Routing	Dynamic trailer routing itineraries are introduced; method: heuristics
Nishimura et al (2004)	Container Yard Trailer Routing	Same as in Nishimura et al (2001)
Reveliotis (2000)	Dynamic AGV routing	Formulated as an "AGV structural control problem"; "structural control policies" are devised
Taghaboni-Dutta and Tanchoco (1995)	Dynamic AGV routing	Devised *incremental* dynamic routing strategies; verified results via simulation
Zhang et al (2002)	CRSP	Objective: minimize total workload overflow; method: Mixed IP.
Zhou et al (2006)	DBAP	Method: genetic-algorithm-enabled heuristic

Perspectives of DS & DM in OCI OR

- There are several factors that fuel our cautious optimism re the perspectives of DS & DM in OCI OR.

- First, the industry is going well (please refer to the statistics in the beginning).

Perspectives of DS & DM in OCI OR (2): OR in container shipping

- Second, trends signify that the prospects of OR/MS (not necessarily dynamic techniques) in general are rosy due to the following trends:
  - *New generation of planners*.
  - *Advances in IT*.
  - *Developments in theoretical aspects*.
  - *Mergers, collaborations and investments leading to larger operational fleets and more elaborate networks*.
  - *The ubiquity of the internet*.
  - *The need for efficient intermodal supply chain networks*.
  - *Explosive growth of sector and increased competition within sector*.

Perspectives of DS & DM in OCI OR (2): Technological advances

- As we observed in the reviewed applications, a significant body of dynamic OR applications in the OCI are thanks to new technologies, which encouraged the study of dynamism.
  - Electronic Data Interchange (EDI)
  - Global Positioning Systems (GPS)
  - Geographic Information Systems (GIS)
  - Intelligent Transportation Systems (ITS)
  - World Wide Web (WWW)
  - Extensible Markup Language (XML)
  - Radio Frequency Identification Technology (RFID)
  - Sensors
  - Automated Port Technology (e.g., AGVs and ALVs)
  - (Real-time) Data Mining
  - Faster computational times
- These technologies facilitate the ability to process real-time information and will stimulate further research in this area.

Dynamic liner vessel routing

- One would not expect applications dynamic liner vessels routing to arise since containerships operate according to a published itinerary known well in advance.

- By contrast, we believe that thanks to new technologies, dynamic liner vessel routing applications will come into sight in the future broken down into two broad categories:
    - environmental routing
    - the cargo booking problem
    - Service reliability

Dynamic vs. static solutions and problems

Q: “Do dynamic models outperform static ones in OCI applications?”

Answer A: Yes

- For the yard trailer routing problem, Nishimura et al (2005) show that a dynamic routing strategy is superior to a static routing strategy.
- In another problem, that of loading a multi-compartment vehicle, Bukchin and Sarin (2006) report that “the dynamic approach is superior to the static approach when a discrete time scale is considered. However, even when the discrete time scale constraint is relaxed, the dynamic approach still provides better results for relatively long cycle times.”
- Moreover, we think that the dynamic BAP resembles more the reality than the static BAP.

Answer B: No

- Grunow et al (2005), in their study of AGVs dispatching state that “the pattern-based off-line heuristic proposed by the authors clearly outperforms its on-line counterpart”.
- In strategic problems, dynamic models could be ‘tricky’ insofar as a dynamic context may cause apparently excessive use of resources that are projected to produce beneficial results in future periods.

Dynamic vs. static solutions and problems

The correct answer seems to be: Answer C: We do not know yet!

- On the whole, we believe that whether a dynamic model is more suitable for a problem is dependable on the type of problem and on the type of data of the underlying instances.

- Dynamic models are apposite in a highly dynamic planning situation where only lacking information about upcoming actions is available.

- Apart from the type of data, we should examine whether the static problem or the dynamic one is closer to the real problem.

System Dynamics Potential

- System dynamics is an overlooked methodological tool in the study of the OCI.
- System dynamics, introduced by Forrester (1961), is a methodology for studying and managing complex feedback systems, such as one finds in business and other social systems.
- System dynamics differentiates itself from system thinking in the sense that the former takes the additional step of constructing computer simulation models to confirm that the structure hypothesized can lead to the observed behavior and to test the effects of alternative policies on key variables over time, while both share the same causal loop mapping techniques.
- System dynamics application to ocean shipping is at its infancy with the a few exceptions (see for example, Dikos et al, 2006; Engelen et al, 2006; Alvarez et al, 2006; Munitic et al, 2003).
- We are not knowledgeable of any system dynamics application within the OCI.
- We think that system dynamics should be exploited in the study of the highly cyclical container industry.

Conclusions

- Based on the review and the subsequent analysis, we believe that a few, yet significant, publications have appeared in the field.
- Clearly, the utilization of DS in carriers' problems is less spectacular than in ports'. This is explained by the fact that the real planning problems of the ports match better the characteristics of dynamic methods and the truth that port problems are more extensively studied in general so far.
- In any case, the growth in the literature significantly lags the revolution that seems to be taking place in some of the related technologies.
- The latter, among other factors, fuels our cautious optimism regarding the future of dynamic systems in the OCI.

Directions for further research

- Dynamic liner vessel routing
- System dynamics
- Compare the efficiency of dynamic vs. static methods in certain real OCI problems (in terms of objective function and with respect to computational time)

Directions for further research (2)

- In closing, we deem it is imperative to define –beyond the OCI- what exactly dynamic, semi-dynamic, and static models are.
- This issue has been addressed in the literature; still confusion persists.
- The degree of dynamism is a concept that could prove helpful in this (see, Madsen, 1998).
- When reviewing several articles, we observed many publications assert being dynamic without being *inherently* so.
- We think that this delineation would stimulate further research in this area.
- Hopefully, this paper could have the same effect.

Any questions?

Thank you for your attention!!!

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