Process Design: Economics and Mathematics in Business

Inaugural address delivered in an abbreviated form by Dr. Iris F.A. Vis in acceptance of the position of Professor of Industrial Engineering within the Faculty of Economics and Business at the University of Groningen on November 8, 2011.

Mr Rector,

1. Introduction

In general terms, one can say that the field of Industrial Engineering is concerned with analyzing and designing processes. Giving my inaugural address today can be seen as a process. The design phase of this process began several months ago with the writing of this address. The main design variable was the selection of subjects to be discussed; additional variables include the number of words per topic and the total number of words to be used. Finally, there is an contingency variable: the percentage of written text that will actually be read during the address.

The final design must also meet several constraints. There is a limited amount of available time. There are also constraints related to the geographic location of this event. For example, in Groningen, people are only acknowledged in the written version of the speech, but not in the spoken text. This provides additional time for professional reflection in the time available.

Producing a good design requires data that can be used as input to the design. One such data element or parameter is the number of words per minute that can be spoken. Once the number of words has been fixed in the design, then the rate of speech will ultimately determine the duration of the process. Data can be obtained by taking measurements during similar processes and through interviews with experts. In order to select the best design, the processing time may also be estimated by performing simulations across a variety of scenarios or different designs. At the end of this design phase, the implementation phase follows – which you are now witnessing.

The field of Industrial Engineering is concerned with the design, development and installation of integrated systems of people, materials, information, equipment and energy. Using specialized knowledge and skills from the exact and social sciences, together with principles and methods from engineering, researchers specify, predict, and evaluate[1].

We define systems as individual organizations or parts of organizations as well as networks of organizations working together to provide services and products to customers. Industrial Engineering functions effectively as a bridge between business and engineering. The Dutch translation is "Technische Bedrijfskunde". In general business programs, and programs like Econometrics and Technology Management, students learn about the issues and challenges that can be solved with methods from industrial engineering.

Much of the research conducted within Industrial Engineering focuses on developing models and methods to make good decisions in designing, improving and implementing systems. Based on my

1 Institute of Industrial Engineers, http://www.iienet2.org/

background and interests, my contribution will be in applications where Operations Research is an important component. In addition, the placement of this position within the Faculty of Economics and Business Administration provides me with the unique opportunity to leverage multiple disciplines in my research; as can be seen in the title of this lecture.

Humans form an important link in most systems. The employees of an organization contribute to the delivery of a product or service. The success of any organization depends on the number of customers that can be attracted and served. This applies to organizations in the manufacturing, distribution or service sectors, both private and public, both for profit and non-profit. A dissatisfied customer will - if possible - leave the system looking for alternatives. This yields a loss to the organization in terms of both finance and reputation[2]. When designing processes, a trade-off must be made between efficiency and customer satisfaction. In this inaugural address, I will discuss some possible strategies and associated methodologies that serve to help find this balance.

2. Process design and control

A process is a network of activities that are performed by machines or employees based on available information. The evaluation of products or services by customers is based on a combination of the following four attributes: cost, delivery times, quality and variations. The providing organization uses parallel measures, namely the cost, lead times, flexibility and quality delivered to judge their products or services[3].

Developments in the design of processes run in parallel with technological developments and changes in customer requirements. While time does not permit me to provide all of the details, I will present some key points in the history of Industrial Engineering. This field originated from the school of scientific management[4]. About a century ago, Frederick Taylor presented methods and techniques to efficiently organize the activities performed by employees in the transformation from input to output. The main objective was to increase productivity and to create economically viable organizations. One innovation in productivity was mass production via the assembly line - a strategy successfully applied by Henry Ford in the production of the 1908 Model T automobile. Prices fell from $ 950 in 1909 from $ 360 in 1916 to $ 290 in 1926. In that year Ford produced half of all cars in the world. From a customers' point of view, the Ford cars received a good score on the properties of cost and delivery time. The chosen design procedure was clear: "Any customer can have a car painted any color that he wants so long as it is black" [5,6]. Variation in the design was out of the question. Mass production was successfully implemented in other industries as well.

The automotive industry is also the originator of another major development in the design of processes. Beginning in 1948, Toyota has been developing a concept called lean manufacturing. Lean is the set of methods used to identify and prevent waste. The main objective is to improve the quality and delivery times while lowering costs. The waste that is removed in a lean process, can literally be a waste of materials within the production environment. However, the waste can also include delays in the process, mistakes and unnecessary costs. For Toyota, the direct result was that cars could be

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2 Anupindi, R., Chopra, S., Deshmukh, S.D., Mieghem, J.A. van, Zemel, E. (2012), *Managing business process flows*, Prentice Hall, New Jersey.
3 Anupindi, R., Chopra, S., Deshmukh, S.D., Mieghem, J.A. van, Zemel, E. (2012), *Managing business process flows*, Prentice Hall, New Jersey.
4 Davenport, T. (1990), The New Industrial Engineering: Information Technology and Business Process Redesign, *Sloan Management Review* 31(4), 11-27.
5 Anupindi, R., Chopra, S., Deshmukh, S.D., Mieghem, J.A. van, Zemel, E. (2012), *Managing business process flows*, Prentice Hall, New Jersey.
6 The New Encyclopædia Britannica (1998), Volume 21 Macropædia, 15th edition.

produced in relatively low volumes at competitive costs. This allowed the customer a choice when specifying product characteristics. This strategy reversed the conventional logic of mass production.[7]

Service companies have known since their creation that customers interact with the design of processes. Producers and distributors, however, struggle with exactly the same interference. Companies must find their way between what the customer expects and the efficient organization of their processes. The influence of clients can be noticed in the variation and uncertainty of the clients' behavior[8]. This is reflected in ordering patterns, desired product features, delivery times, complaints, returns, and so on. Companies are forced to balance between the desires of the customer and their production capabilities. For the company, a primary focus is having a high adoption rate-- after all, the customer is not interested in the operations within the company, but only the end product.

In my view, the key is finding a balance between encouraging customers to purchase efficiently produced products and services while redesigning processes to accommodate the needs of customers. The option of successfully encourage customers is relative. After all, encouraging a person only works if that person wants to be encouraged. Companies must, therefore, look for those aspects that the customers want. Professor Van Goor concluded, in his farewell speech on September 30, 2011, that logistics can learn from commerce. To find the right strategies require working in close cooperation with the marketing department while designing the processes. The goal is to focus more on how to tempt customers to desire the result of an efficient process instead of redesigning the process in response to marketing actions and assortment decisions. This requires the use of real-time information on customer requirements, customer behavior and the goods needed. Current technology makes it possible to continuously monitor these aspects. An example is the use of online customer reviews in forecasting the expected demand for a product. Goods, for example, to be transported in a container, can be monitored by means of automatic identification. Satellites and fixed equipment register the containers en-route and provide the necessary information required fortransshipment and customs processes.

3. Methodology

The coherence of the disciplines mentioned – economics, mathematics, and business -is also reflected in the research strategies and methodologies for process design; such methods include: operations research, operations management, supply chain modeling, business process improvement and business process re-engineering[9,10,11,12]. Each of these methods requires the combination of qualitative and quantitative research strategies. As program director of the two master programs Supply Chain Management and Technology and Operations Management of the Department of Operations it is also my goal to teach students to appreciate and use this combination of research methods.

When working in the domain of industrial engineering, the starting point is almost always a practical problem. The first step in addressing this problem is to translate the problem into a conceptual model. This step can be made based on information about the goals of the organization or network. In addition, an analysis of the inputs and outputs of the process must be performed to ascertain the

7 Holweg, M. (2007), The genealogy of lean production, *Journal of Operations Management* 25, 420-437.
8 Frey, F.X. (2006), Breaking the trade-off between efficiency and service, *Harvard Business Review*, November, 92-101.
9 Mitroff, I.I., Betz, F., Pondy, L.R. and Sagasti, F. (1974), On managing science in the systems age: two schemas for the study of science as a whole systems phenomenon, *Interfaces*, 4(3), 46-58.
10 Naim, M. M., and D. R. Towill. 1994. Establishing a Framework for effective Materials Logistics Management. *International Journal of Logistics Management* 5 (1):81-88.
11 Bertrand, J.W.M., Fransoo, J.C. (2002), Operations management research methodologies using quantitative modeling, *International Journal of Operations & Production Management*, Vol. 22 No. 2, 2002, pp. 241-264.
12 McKay, A., Radnor, Z. (1998), A characterization of a business process, *International Journal of Operations & Production Management*, Vol. 18 No. 9/10, 1998, pp. 924-936.

core elements. Qualitative research techniques such as surveys and interviews form the basis in finding these answers. Through the careful selection of a set of realistic assumptions, the conceptual model is, in the second step, translated into a scientific model. In the third step, a solution method will be derived that can find solutions to the problem. Formal proof or validation is required in this step. In the final step, the derived solution is implemented. Once the scientific model is introduced, the research techniques become quantitative, ranging from analytical to empirical research.

The role of information and communication technologies (ICT) in designing processes is increasingly important[13]. In developing solution methods, the role that ICT can play in obtaining well-organized processes merits consideration. This can either be through the use of historical data or by using real-time information.
Regardless of the method by which the data was collected to establish the problem's parameters, an important consideration in developing a solution method is whether to use a heuristic or optimal/algorithmic approach[14]. This choice must be made each time (see Figure 1). Algorithms are interesting because they lead to an optimal solution. A mathematical proof of optimality and a description of the complexity are important attributes in publishing and implementing algorithms. However, when making tactical or operational decisions, the speed of the solution mechanism is also important; algorithms are often not fast enough. Heuristics are favored if the mathematical model that has been formulated no longer reflects reality or if an optimal approach requires too much computing time. Heuristics also have the benefit that they may be easier to communicate within the organization than an exact algorithm. In order to justify the use of a heuristic, however, it is necessary to undertake an extensive validation procedure to show that statistically, the heuristic is reliable.

Practical validation is used to show that while the developed heuristics may not be provably optimal, they are at least providing results within the desired bounds for practical purposes. A good balance must be found in research between the derivation of theoretical solution methods and techniques that are immediately applicable to generate realistic solutions. This holds for heuristics as well as algorithms. Wolsey noted in 1979 that the field of Operations Research has more algorithms than applications[15].

My current research, performed with fellow researchers, holds many examples. Roel van Anholt studied, in his doctoral research, design decisions that play a role in optimizing the inventory management at banks[16] and ATMs[17]. Processes for service environments such as libraries, are key themes in projects currently performed by PhD candidate Susanne Wruck[18] and post-doctoral researcher Remco Germs. Another example comes in the form of Dr. Marco Bijvank's PhD thesis aimed at solution methods for avoiding empty shelves in supermarkets[19].

In the second part of my address, I will discuss two new research topics. Both topics are focused on finding the balance between the initial customer request and strategies to tempt the customer by products and services resulting from more efficient processes. For each of the themes, I present relevant research questions.

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13 Davenport, T. (1990), The New Industrial Engineering: Information Technology and Business Process Redesign, *Sloan Management Review* 31(4), 11-27.
14 Zanakis, S.H. , Evans, J.R. (1981), Heuristic "optimization": why, when, and how to use it, *Interfaces* 11(5), 84-91.
15 Wolsey, R.E.D. (1979), Pragmatism triumphant or past sophistication and future elegance. In: Haley, K.B. (Ed.), *Operational Research '78*. North Holland, Amsterdam, pp. 80–86.
16 Vis, I.F.A. (1997), Kasvoorraadbeheer bij aangesloten banken, *Master Thesis*, Leiden University.
17 Van Anholt, R.G., Vis, I.F.A. (2010), An integrative online ATM forecasting and replenishment model with a service level constraint, *proceedings of The 1st International Conference on Logistics and Maritime Systems* (LOGMS 2010).
18 Wruck, S., Vis, I.F.A., Boter, J. (2011), Batching Management in Warehouses with High Product Returns: Development and Discussion of Approaches and Models, *under review*.
19 Bijvank, M., Vis, I.F.A. (2011), Lost-sales inventory theory: a review, *European Journal of Operational Research* 215, 1-13.

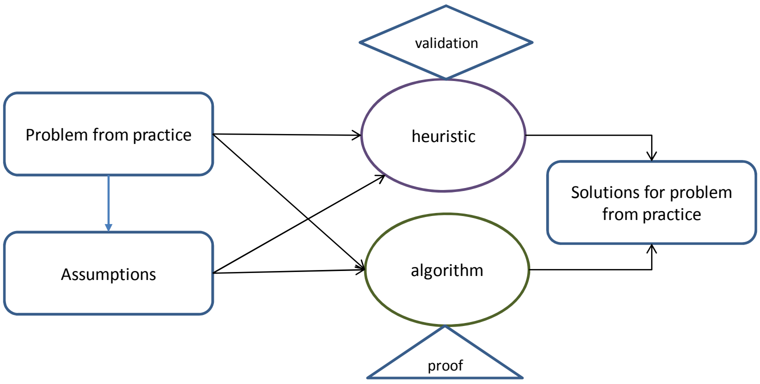

Figure 1: Heuristic or Algorithm

4. Social media as strategy in the order process

Our daily vocabulary is peppered with new and modern verbs: Twittering, facebooking, hyven, and so on. I myself am not active on twitter, but the enthusiastic stories of Jerry van Leeuwen[20], made me aware of the new possibilities available in process design. Marketing departments have long seen the power of virtual networking and real-time information in the sale of goods and services. Through the power of social media, the customer can be involved in generating ideas and testing prototypes to give feedback in all phases of the product life-cycle. It appears that a greater involvement of customers at the beginning of the product life-cycle leads to greater acceptance[21]. In principle, all departments within organizations deal with social media[22]. However, the impact varies as shown in Figure 2.

Demand forecasting is an important aspect in supply chains and is widely supported by the technologies available to track customers' behavior on the Internet. User clicks on websites, search terms and online reviews form an important source of data in predicting sales. Research shows that a clear link exists between the life cycle phase of the product (e.g., design or launch) and type of data to be used[23]. Advanced mathematical techniques are needed to select or mine the right data from this large quantity of data and translate it into a useable forecast.

The use of social media as a strategy to persuade customers to make concessions on specific product characteristics or the delivery goes one step further. One possible mechanism lays in the fairly new concept of group-wise buying by customers. By using this concept, the manufacturers may be able, in

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20 directeur ScanYours.com, eBusiness Consultancy, http://www.scanyours.com/
21 Alon, A., Gupta, A.J. (2011), Using social media to drive product development and find new services to sell, in: *The Social Media Management Handbook*, Smith et al. (eds.), Wiley, New Jersey, 104-119.
22 Smith, N. en Wollan, R. (2011), The power and business risks of social media, in: *The Social Media Management Handbook*, Smith et al. (eds.), Wiley, New Jersey, 3-15.
23 Reijden, P. van de, Koppius, O. (2010), The value of online product buzz in sales forecasting, *ICIS 2010 Proceedings.* Paper 171.

part, to return to the success of mas production or lean manufacturing. For example, computer manufacturer Dell introduced the "Dell Swarm"[24]. A consumer may initiate a swarm by defining a specific configuration for a computer. Other consumers may join the group. The group members then work together to agree on the specifications of the computer to order. This mechanism works because each swarm member has the same goal – obtain a home computer with the desired specifications at as low a price as possible. The larger the group, the more discount Dell computer is willing to offer. Group members can use social media such as facebook and twitter to share information and call other consumers to join. In a sense, the customers serve as agents of the company to pull a group of customers together and coordinate delivery times and specifications. The resulting cost savings in both the production and transportation are shared between customer and company. Preliminary research shows how to design these mechanisms to serve as marketing tools while also permitting the company to turn a profit [25].

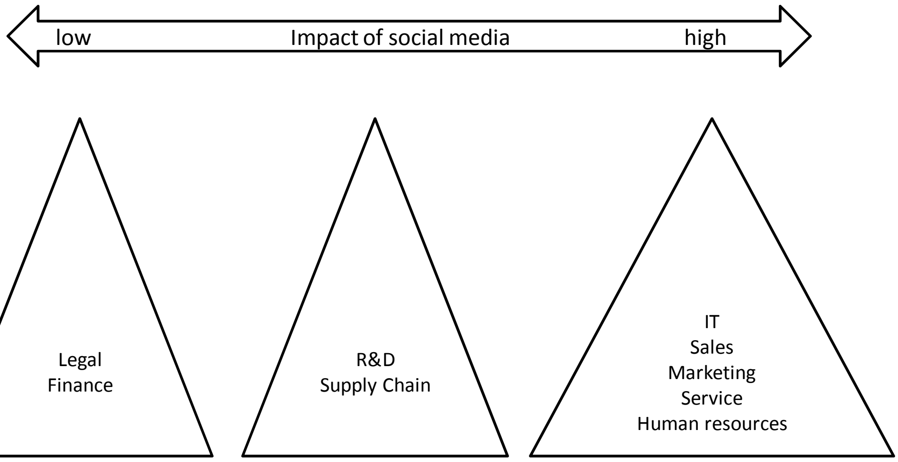

Figure 2: the impact of social media on departments in organizations
(Smith en Wollan, 2011[26])

For companies, it is important to achieve an efficient use of available resources. Loyal customers who frequently make bulk orders are important, as can also be seen in the previous example. Translating this same idea to a service environment, where tasks have to be performed more efficiently with fewer staff and resources, is an interesting research proposition. Take for example a library. A customer may borrow a fixed number of books per visit. After reading those books s/he will return again to call on the resources of the library. By examining the transaction data of customers, advice on suggested books to borrow can be prepared;or as Amazon.com puts it "Customers Who Bought This Item Also Bought..." . However, there is an interesting possibility with library books that does not exist for the sale of books. Based on analysis a book may be recommended to the client. The customer is of course free to not read the book. However, if the client does select the recommended book, the expected timing of the next visit to the library will shift. By carefully selecting the

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24 http://www.dellswarm.com/uk/index/landing
25 Jing, X., Xie, J. (2011), Group Buying: A new Mechanism for selling through social interactions, *Management Science* 57(8), 1354-1372.
26 Smith, N. en Wollan, R. (2011), The power and business risks of social media, in: *The Social Media Management Handbook*, Smith et al. (eds.), Wiley, New Jersey, 3-15.

recommended books, the library has control over the number of visits that this client makes to the library; a reduction in visits may result in savings. For the concept to be successful, however, we need the answers to some questions. What are the right books to suggest to each customer? Which customers will appreciate this? What is the appropriate collection of books to maintain in the library? Will sufficient choice remain on the shelf or should the collection be extended? How should the internal processes in the library be organized?

5. Reliability in transport networks

A transport network provides the structure and infrastructure for a load to move from point A to point B. Shippers have choices regarding the modes of transport to use: by boat, train or truck. Intermodal transport can also be selected allowing a combination of modalities. This choice must be made in advance. This means that in the event of delays, disruptions or barriers, the timely delivery of goods can no longer be guaranteed.

Synchromodal transport[27]*,* is one of the key issues to address in the area of logistics, as noted by Topteam Logistics. Synchromodal transport uses real-time information to shape the transport network based on the information provided by operators regarding possible delays. The coordinator uses this information to update mode choice decisions made for each load. Through cooperation, as opposed to competition in the network, less empty vehicles will be need and flexible and sustainable transport can be achieved.

A recent example shows the necessity of a concept like synchromodal transportation. On January 13, 2011 a ship capsized in the River Rhine. As a result, at this point no ship in the river could pass. Salvage work and the associated block lasted one month. During this period, a queue of 400 boats formed[28]. In October 2011, it was calculated that the cost was at least 50 million Euros. Of this amount, 14 million Euros were paid by the barge skippers and 26 million Euros fell on the shoulder of the shippers. The reputational damage suffered by this sector was not included in these calculations[29]. Shippers were obliged to seek other forms of transportation. Other suppliers were approached while sales fell and stocks increased in distribution networks.

A Synchromodal network experiences less problems in such situations, because it is inherently flexible. Shippers have the option to immediately turn to other modalities. Topteam Logistics indicates that an open IT platform where all stakeholders share information, is necessary for success. In addition, data from geographic information systems and GPS are an important source of information for continuous monitoring of freight flows and their disturbances. It is important to determine in advance what types of data must be available for properly managing synchromodal networks. Notes attached to the freight need to contain the right information to allow the right decisions.

To ensure the success of this newly proposed structure of transport networks and their management, the shipper must be convinced of its usefulness and should be ready to release the control of his/her shipment. The client will specify only the origin and destination of the cargo along with the desired time window for delivery. An important incentive for the acceptance of this method of control is the level of flexibility and reliability. The central research questions are, therefore, how can synchromodal networks be designed such that customers are encouraged to make use of the strategy and the transport providers can realize benefits from coordination?

In the following part of my address, I describe the research steps that I believe are the basis of a good network design with dynamic route allocation methods based on real-time information (see Figure 3). Support from theGroningen Seaports enables us to start working

27 Topteam Logistiek (2011), Partituur naar de top, *Adviesrapport Topteam Logistiek*.

28 http://www.rtl.nl/(/actueel/rtlnieuws/buitenland/)/components/actueel/rtlnieuws/2011/02_februari/08/buitenland/file-bij-omgeslagen-tanker-opgelost.xml

29 http://nos.nl/artikel/287405-stremming-rijn-kostte-zeker-50-mln.html

on this right away. In essence, we distinguish the following steps: (1) Determining the nodes in the network based on historical data and forecasts; (2) Defining the necessary logistics system; (3) Establishing the necessary infrastructure and hinterland connections; (4) Formulating management concepts that allow using real-time information to schedule and reschedule loads and transport routes; and(5) Formulating strategies for designing horizontal and vertical cooperation in the network. Formulations for measuring performance in terms of sustainability and reliability will be derived in Project 3 and serve as a basis for comparing and selecting designs.

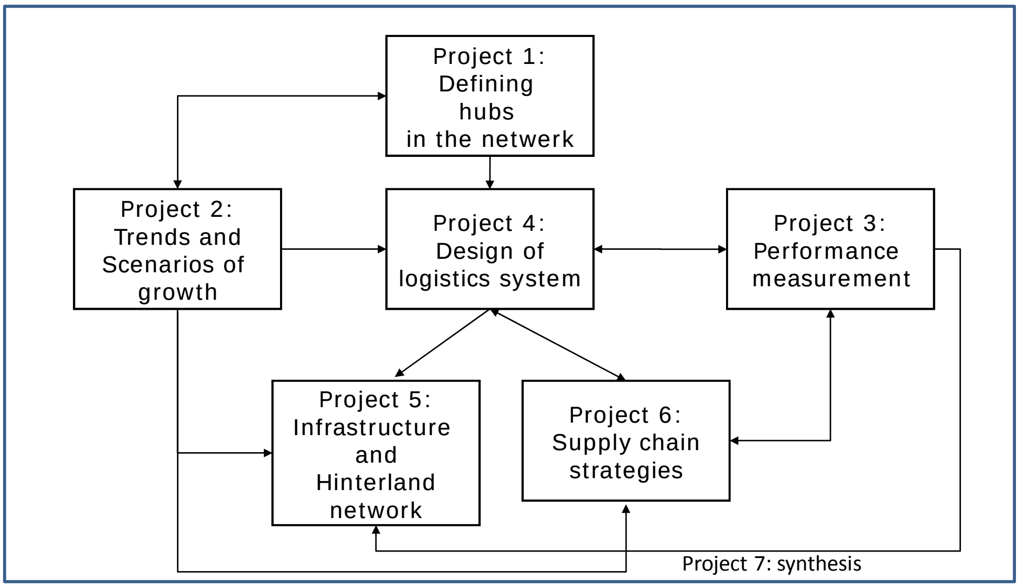

Figure 3: Schematic representation of research design

Project 1: Defining hubs in the network

The goal of this project is to integrate nodes and functionality in synchromodal networks. Therefore, we start by describing the functions, roles and activities that a node (such as a port) can perform. We seek here the analogy with the model that describes the life cycle of a product. At every stage of growth, a node has a different function within the network, different hinterland networks, infrastructure, and other relevant parties associated with the node. A description of all life-cycle phases, with the factors and network partners in each phase, will serve as important input for selecting the nodes in the network. We will start with a literature review. In addition, observations at many ports (main ports and regional ports), airports and rail terminals will be undertaken.

Project 2: Growth scenarios

When designing synchromodal networks, knowledge of growth scenarios is of great importance. The goal of this project is to derive a methodology to find these growth scenarios (see Figure 4). Based on the current flows at regional, national and international levels, predictions of future flows can be made by means of mathematical techniques and GIS analysis. We also identify the following factors as important in making forecasts: (1)

Expected developments in freight transport based on forecasts regarding the usage of modes of transportation and infrastructure; (2) Anticipated changes in institutional, political, social and economic factors; and (3) Identification of market opportunities.

As an example of the first aspect, we highlight the planned widening of the Panama Canal in 2014. This change in capacity from 4,400 TEU[30] ships to ships of 12,600 TEU will result in changes to shipping routes. This can be explained as follows. Two thirds of the U.S. population lives on the East Coast. Asian products currently move to the East Coast via land routes (truck or rail) due to the comparative efficiency (both in terms of cost and time) of these modes. With an increase of capacity at the Panama Canal, these goods will likely remain on board a ship passing through the canal and on to the ports of the East Coast. Cost might decrease, but delivery times may increase. Questions regarding the nature of this trade-off remains and this example serves to emphasize the need to include expectations regarding the use of all modes over roads, rails, and waterways in forecasting[31].

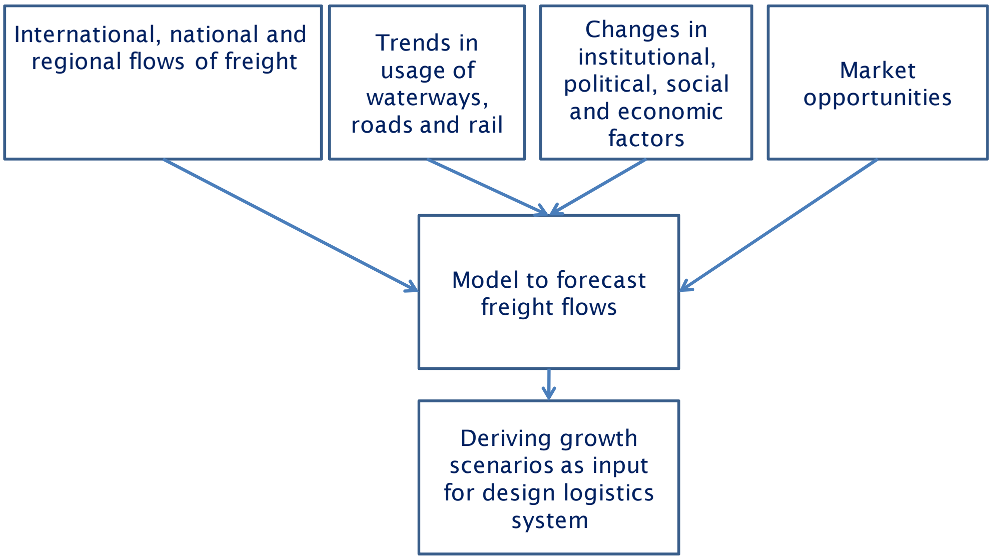

Figure 4: conceptual model to derive growth scenarios.

Projects 4, 5 and 6: Design

The design of a synchromodal network requires an emphasis on both the internal flows (e.g., within a port) as well as the flows between the various nodes (e.g., airports, seaports, rail terminals).

A Synchromodal network can be modeled as a dynamic multi-commodity network[32]. In a conceptual model, we can describe the problem as follows. The goal is to route different

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30 standaardmaat Twenty-foot equivalent unit (TEU), container met lengte 20ft

31 Jones Lang LaSalle (2011), The Panama canal's impact on U.S. industrial real estate, white paper, http://www.joneslanglasalle.com/ResearchLevel1/Panama_Excursion-JLL.pdf.

32 Ahuja, R.K., Magnanti, T.L., and Orlin, J.B. (1993), *Network Flows, theory, algorithms, and applications*, Prentice Hall, New Jersey.

modalities to transport a prescribed set of non-homogeneous jobs. Each delivery has a specific time window, the necessary transport capacity and an origin and destination. We are dealing with an heterogeneous fleet of vehicles, each with their own route through the network at different speeds. A stop can be made at nodes in the network. There it is possible to transship loads from one mode of transportation to another. Related to each type of movement, we consider costs– related to time and operational costs. Each hinterland connection has a transport capacity that can vary per mode of transportation. The time aspect can be linked to each node by appointing arrival and departure times. By mapping these connections for every movement in time, we make multiple copies of the underlying network. Given this network, we then need only to impose constraints to find feasible flows. Such constraints include: capacity constraints on the bundling of freight flows, flow balancing constraints ensuring that the cargo that enters a node leaves it again, and load-splitting constraints to ensure that one load will not be moved by more than one mode of transport on one link in the network.

Solution methods should be developed, which can be used for making decisions such as:

- What is the best route from start to end?
- What flows can be combined?
- Which mode(s) should be chosen to transport cargo?
- At what times should the transportation of any shipment start or end?
- In which node(s) will transshipments take place?

Finding a solution in the network is based on real-time information. This means that the availability of hinterland connections and hubs can be displayed and if necessary set to zero. In addition, the real-time information used in the allocation of modes can be used to reconsider this decision. It is important to display the availability of nodes and connections and to be able to express lost time in costs to make an economic assessment. The quality of the solution can be measured by the number of orders that are delivered on-time, the potential reduction in the number of empty movements , the robustness of the solution to change modes of transport at any time, a reduction in costs and an increase in throughput.

In Project 5, the hinterland network is defined that is needed to reach all nodes. In addition, it is indicated what demands are posed to the underlying infrastructure of the network. For example, one can think of the capacity of locks in rivers. Project six defines strategies for horizontal and vertical cooperation in networks. Such cooperation is needed to join forces and work together within the proposed logistics system to deliver reliable services. This can lead to efficiencies and a sustainable partnership.

6. Conclusion

From this inaugural address it is hopefully clear that an important objective in providing products and services is to encourage consumers to purchase reliable products and services that are the result of efficient and economically sound processes. By following the steps outlined in the research plan, we can design a synchromodal transport network that provides faster, cheaper, more reliable and more flexible transport. The challenge is to find ways to properly connect the various pieces such as economic considerations, mathematical techniques, data availability and customer requirements.

I have spoken.