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Schedule Unreliability in Liner Shipping: Origins and Consequences for the Hinterland Supply Chain

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Despite claims by shipping lines that most of their containerships operate on fixed-day weekly schedules, a large survey recently revealed that over 40% of the vessels deployed on worldwide liner services arrive one or more days behind schedule. Broadly speaking, the survey found relatively low average schedule reliability levels overall across the industry, but with strong variations between the schedules of different liner carriers and between different trade routes. Low schedule reliability can be caused by a number of factors, many of them beyond shipping lines' control, and can have serious consequences for various actors in the supply chain. This paper focuses on the impact of decreasing schedule integrity on one of these actors, namely shippers/consignees. More specifically, we present a case study to illustrate the impact of schedule unreliability on the level of safety stock that should be kept by a manufacturer who sources spare parts from overseas. It is shown that an improvement in schedule reliability can lead to significant cost savings for the company under consideration.
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INTRODUCTION

As argued by IBM Business Consulting Services (2005), container shipping lines are facing several challenges in today's highly competitive environment, one of which is an increasing demand by customers for greater reliability of container shipments at lower total costs. This is acknowledged by Psaraftis (2004), former CEO of the Piraeus Port Authority, stating that 'the name of the game of all major container lines is their ability to meet their schedules, as they incur enormous costs, both real and intangible, in case they do not'. However, an in-depth schedule reliability survey performed by leading maritime analyst Drewry Shipping Consultants (2006a) and based on the monitoring of no less than 5,410 vessel arrivals on 23 different east/west and north/south trade routes between April and September 2006 (ie about 200 vessel calls per week) revealed that more than 40% of the vessels deployed on worldwide liner services arrived one or more days behind schedule. To be more precise, the percentage of on-time vessel calls[1] was about 52%, with 21% of the vessels arriving 1 day late, 8% arriving 2 days behind schedule and no less than 14% of the vessels calling their port of arrival 3 or more days late (the remaining 4% arrived 2 or 3 days *before* their scheduled ETA). These observations are obviously in stark contrast with claims of shipping lines that most of their containerships operate on fixed-day weekly schedules.

Although the Drewry survey found low reliability levels overall across the industry, strong variations were observed between the schedules of different liner carriers. Of the 65 international shipping lines whose vessel schedule reliability was monitored, 15 enjoyed on-time arrivals of 60% or more, while 12 carriers scored between 50% and 60%. No less than 38 carriers had on-time arrivals of less than 50% (of which 21 carriers even scored below 40%). Individual schedule reliability percentages ranged between 4% for the least reliable shipping lines and above 90% for the best-performing carriers over the period of the survey. Of the main east/west carriers, Hatsu Marine, Italia Marittima (both belonging to the Evergreen Group), Safmarine and Maersk Line enjoyed high schedule reliability levels, whereas K-Line, China Shipping Container Lines and Mediterranean Shipping Company were some of the carriers with below-average schedule integrity. For the worst-performing carriers, the average deviation from the ETA easily amounted to 3 days or more.

Unsurprisingly, the survey also revealed significant differences between reliability levels on the different liner trade routes. Routes with on-time arrivals of 70% or more included North America/Indian Subcontinent/Mideast/Red Sea and North America/Hawaii/Guam/mid-Pacific. On the other hand, the Asia/East Coast South America, Asia/West Coast South America, Europe/Med/Australia/New-Zealand/South Pacific, Europe/Med/West Coast South America, North America/Caribbean/Central America and North America/East Coast South America trades each experienced reliability levels of (well-)below 40%. On some trade routes, transit time delays of 3 days or more were found to be the rule rather than the exception. It should be noted, however, that for some trade routes the results are based on very small sample sizes.

The aim of the present paper is to investigate the origins of liner schedule unreliability and its impact on the hinterland supply chain. The paper is organised as follows: in the following section, an overview is provided of the various factors causing unreliability in liner schedules. Specific attention is paid to the development of demand for container services and supply of container-handling capacity. Next, we investigate the implications of decreasing schedule integrity for various actors throughout the supply chain, that is, shipping lines, terminal operators, inland transport operators and shippers/consignees. The latter actors are dealt with in more detail in the next section, where we present a case study to illustrate the impact of schedule unreliability on the level of safety stock that should be kept by a manufacturer located in South Africa who sources spare parts from South America for his production process. It is shown that an improvement in schedule reliability can lead to significant cost savings for the company under consideration. The final section contains the main conclusions of the paper and outlines some avenues for further research.

FACTORS CAUSING LINER SCHEDULE UNRELIABILITY

The low reliability of liner schedules can be explained by a number of factors. Common reasons for vessel delays include bad weather at sea, congestion or labour strikes at the different ports of call, as well as knock-on effects of delays suffered at previous ports. More serious delays, leading to significant time-losses for the cargoes involved or even the loss of the cargo altogether, can be caused by fire incidents (cf. the serious fire incident onboard the 'Hyundai Fortune' in the Gulf of Aden in late March 2006), ship collisions or ship groundings (cf. the 'APL Panama' running aground on a beach off the Mexican coastline in December 2005, only to be refloated in early March 2006, or the incident with the 'MSC Napoli' off the UK East Coast in early 2007).

As far as port congestion and labour strikes are concerned, African ports turn out to be among the worst affected. In this respect, it comes as no surprise to see that carriers heavily involved in the African trades, such as Delmas/OTAL, DAL and MACS, feature at the bottom of the table, with schedule reliability levels of 30% or even less. However, even within the same trade route schedule reliability scores were found to vary considerably depending on the individual service and individual carrier. Drewry contends that most liner carriers do not include in their weekly schedules sufficient buffer time for contingencies such as bad weather and port delays, and that some lines regard buffer time as too expensive.

The issue of port congestion and the resulting worsening of schedule integrity can, among other reasons, be explained by an insufficient match between demand for container services and supply of container handling capacity. As far as demand is concerned, UNESCAP (2005) estimates that the total number of full containers shipped on worldwide trade routes (excluding transhipment) amounted to 77.8 million teu for the year 2002. This figure is expected to more than double to 177.6 million teu by 2015, which represents an average annual increase of 6.5%. During the period 2002–2010, average growth is estimated at 7.5% per year, falling to 5.0% per year in the following 5 years. More specifically, container volumes shipped on worldwide trade routes are expected to develop as follows (see also Global Insight *et al*, 2005):

- Volumes on the *east-west trades* (ie Transpacific, Transatlantic and Asia/Europe) are expected to increase from 34 million teu in 2002 to 70 million teu in 2015, representing an average annual growth rate of nearly 6%;
- Volumes on the *north-south trades* (linking the major production and consumption centres of Asia, North America and Europe with developing countries in the Southern Hemisphere) are expected to show a similar average growth rate, increasing from about 17 million teu in 2002 to about 36 million teu in 2015;
- *Intra-regional trades*, however, are expected to show significantly higher growth during the same period. Mainly as a result of booming intra-Asian trades, they are expected to surge from 28 million teu in 2002 to no less than 72 million teu in 2015, corresponding to an average annual growth rate of 7.5%.

According to Drewry Shipping Consultants (2006b), total throughput handled by the world's container ports (not to be confounded with the trade route statistics mentioned above) increased from about 236 million teu in 2000 to an estimated 442 million teu in 2006 (including empties and transhipment), representing an average annual growth rate of 11%. As Table 1 indicates, transhipment traffic has clearly been the driving force behind growth in container handling in the last decade. As far as the near future is concerned, worldwide container handling is expected to increase further to 627.4 million teu in 2010 (some 42% above the 2006 level), of which 360.2 million teu port-to-port full containers, 94.4 million teu port-to-port empty containers and 172.8 million teu transhipment.

As a result of strong growth on the arterial container trade routes in recent years, and in order to anticipate on future volume increases, many shipping lines have embarked upon ambitious expansion plans to upgrade the capacity of their ship fleets. According to AXS-Alphaliner (2007), 2,622 cellular containerships were deployed on worldwide trade routes at the beginning of

Table 1: World container port traffic and its components

	Total port handling	Port-to-port full	Port-to-port empty	Transhipment
1990	88.0	57.9	14.7	15.5
1995	145.5	93.1	21.0	31.5
2000	236.2	138.1	37.2	60.9
2006 (est)	441.9	255.5	66.2	120.2
2010 (est)	627.4	360.2	94.4	172.8
2006 *versus* 1995	+204%	+174%	+215%	+282%
2010 *versus* 2006	+42%	+41%	+43%	+44%

Source: Drewry Shipping Consultants (2006b)

Table 2: Composition of the cellular containership fleet for selected dates

	01/01/2010*		01/01/2007		01/01/2000		01/01/1995	
Size range (teu)	No.	teu	No.	teu	No.	teu	No.	teu
>7,500	291	2,643,119	147	1,250,003	10	80,822	0	0
5,000/7,499	531	3,120,799	357	2,070,373	68	383,415	0	0
4,000/4,999	550	2,422,251	346	1,529,854	156	682,428	79	345,351
3,000/3,999	364	1,238,329	282	956,165	227	770,410	164	541,516
2,000/2,999	799	2,029,036	648	1,630,850	389	960,443	255	637,502
1,500/1,999	615	1,045,632	466	786,591	327	552,003	198	339,511
1,000/1,499	774	919,329	595	705,600	484	565,073	367	433,533
500/999	931	692,980	722	525,853	539	381,630	336	239,439
100/499	385	122,569	387	123,057	422	132,484	343	107,046
Total	5,240	14,234,044	3,950	9,578,346	2,622	4,508,708	1,742	2,643,898

Source: AXS-Alphaliner (2007)

*Figures based on orderbook as of 1 June 2007. Figures for 01/01/2010 should be treated with care. On the one hand, some shipyards can still accept orders for (small) ships to be delivered during 2009. On the other, the figures assume that no ships are scrapped up to 01/01/2010, which, taking into account the age profile of the current containership fleet, is not very realistic.

2000, providing a total slot capacity of about 4.51 million teu (see Table 2). By the beginning of 2007, these figures had increased to 3,950 ships and 9.58 million teu, respectively. Hence, the total capacity provided by cellular containerships more than doubled in just 7 years' time, representing an average annual increase of 11.4%. Moreover, based on shipping lines' orderbooks as at 01/06/2007, the number of cellular containerships deployed on worldwide trade routes is expected to further increase to about 5,200 units by 01/01/2010, providing a total slot capacity of 14.23 million teu. This equals a massive increase of nearly 50% in just 3 years' time, or 14% per year. To put this in perspective, the capacity increase of 4.66 million teu during 2007–2009 means that a stunning 130,000 teu slots will be added to the worldwide cellular fleet *every month*.

Given the relentless search for cost savings at sea (cf. economies of scale), it is hardly surprising to see that many shipping lines' expansion plans are heavily focused towards large post-panamax (ie 5,000+ teu) containerships. Whereas 78 of such ships provided a total slot capacity of just 464,000 teu at the beginning of 2000, these numbers already amounted to 504 units and 3.3 million teu, respectively, at the beginning of 2007 and are expected to further increase to 822 units and nearly 5.8 million teu by the beginning of 2010. This equals a more than 12-fold increase of the capacity in just 10 years, or an average increase of nearly 30% per year. Whereas 5,000+ teu ships provided just 10% of the total cellular fleet capacity at the beginning of 2000, their share will have increased to some 40% at the beginning of 2010. As Table 2 indicates, the development of the 7,500+ teu segment is even more impressive.

The massive influx of new tonnage in the coming years, and the cascading-down effect triggered by the introduction of large post-panamax ships on the arterial trade routes, will obviously lead to a significant increase in average vessel sizes on the main trade routes. For example, Ocean Shipping Consultants (2006) expects the size of a typical container vessel deployed on the Far East – Europe trade to increase from 4,500–5,500 teu in 2000 to 8,000–9,000 teu in 2010 (ie +70%) and no less than 10,500 teu in 2015 (ie +110%). The increases in average vessel sizes for the other deep sea trades and the feeder trades are somewhat lower, albeit still remarkable (see Table 3).

Whereas shipping lines have clearly prepared themselves to handle the expected increase in container volumes in the short term, the development of additional container handling capacity to meet this demand has lagged behind in some parts of the world. Specifically with respect to North Europe, Drewry Shipping Consultants (2005) found significant delays in many expansion projects related to container handling. In France, for example, the originally

Table 3: Average vessel sizes (in teu) by major container trades for selected years

	2000	2005	2010	2015	2010 *versus* 2000 (%)	2015 *versus* 2000 (%)
Deep sea east/west						
Far East-Europe	4,500–5,500	5,500–7,000	8,000–9,000	10,500	+70	+110
Transpacific	4,500–5,000	5,500–6,500	7,000	8,500	+47	+79
Transatlantic	3,500	4,000	5,000	6,500	+43	+86
Deep sea north/south	2,500	3,000	3,000	3,500	+20	+40
Feeder	550	650	700	850	+27	+55

Source: Ocean Shipping Consultants (2006) proposed date for the opening of the 'Le Havre Port 2000' complex was delayed for 3 years (from 2003 until 2006). Analogously, the first phase of the Deurganckdok in the port of Antwerp was taken into operation in 2005, while this date was originally intended to be 2001. A similar 4-year delay is experienced by the Euromax terminal in the port of Rotterdam (from 2004 to 2008) and the JadeWeserPort in Wilhelmshaven (from 2006 to 2010), while yet even bigger delays are being faced by the Westerschelde Container Terminal in Flushing (at least 5 years delay, if the terminal will be built at all) and the Maasvlakte II project in Rotterdam (start date of operations postponed from 2002 to 2013 at the earliest). In the UK, Hutchison Port Holdings' 'Felixstowe South Reconfiguration' obtained government approval in early 2006 and is expected to be taken into operation in 2008, that is, 2 years behind schedule. Hutchison was also recently given the formal go-ahead for the development of a new container terminal at Bathside Bay in the port of Harwich. Construction work on the first phase of the project is expected to start in 2009 at the earliest, implying a significant delay to the proposed start date of operations of 2004. Finally, DP World's plans for the London Gateway terminal (originally scheduled to open in 2006) only received final approval in May 2007 (with operations expected to start around 2010), while Associated British Ports' plans to develop a new container terminal at Dibden Bay in Southampton (scheduled to open in 2000) have even been cancelled altogether.

The delays or cancellations of the above-mentioned projects have a number of different causes, ranging from internal politics within the port, environmental objections, legal technicalities and objections, investigations by the European Commission into market share implications, to political wrangling over funding, court cases, or to public enquiries and subsequent government considerations of their findings. Overall, the estimated total cost of the approval processes of the different terminal projects listed above is well in excess of half a billion euro. If all these proposed projects would have been realised in accordance with the original time schedule, an extra capacity of no less than 11.4 million teu would have been available in North European ports in 2005. To put this in perspective, this is nearly one-third of the total capacity offered by these ports in 2004 (34.8 million teu).

In view of the above, it should come as no surprise to see that terminal operators active in major European container ports have been witnessing increasing utilisation levels of their facilities in recent years. According to estimates by Ocean Shipping Consultants (2006), 'North Continent East' (=German) and 'North Continent West' (=Benelux and Northern French) container ports experienced utilisation levels of +90% and +80%, respectively, in 2004, obviously resulting in severe congestion problems during peak periods.[2] This is confirmed by HVB Group/Drewry Shipping

Consultants (2005), who state that 'arguably, 2004 was the worst year on record for congestion at the world's container ports' and who indicated in particular the major Benelux ports and some UK ports as European 'congestion hotspots' during 2004. Appleton (2005) argues that, as 90% utilisation levels are exceeded, carriers experience a significant loss in terminal flexibility. In this respect, it is important to note that, without the planning delays of the above-mentioned projects, average utilisation levels at European deep sea terminals in 2004 would have hovered around 68%, significantly lower than the 86.6% experienced in reality.

IMPLICATIONS OF DECREASING SCHEDULE INTEGRITY FOR SEAPORTS AND THEIR ACTORS

It is obvious that increases in vessel size will be accompanied by increasing requirements with respect to the draught of navigation channels at the different ports of call. However, many ports around the world currently dispose of insufficient nautical access to accommodate the largest container vessels under all circumstances. Moreover, those ports that are envisaging deepening programmes to improve nautical accessibility in order to maintain their competitive position (eg Antwerp and Hamburg in Europe) are faced with very time-consuming procedures, both with respect to the approval process as with the dredging activities themselves. This can be expected to lead to a further decrease in schedule reliability over the next couple of years, obviously affecting all players throughout the entire supply chain (see also HVB Group/Drewry Shipping Consultants, 2005):

Shipping lines are faced with increasing operating costs. According to industry experts, an 8,500 teu container vessel ordered in 2003 at USD 80 million (well-below the USD 130 million level observed during the second quarter of 2005) and nowadays being deployed on an 8-week Far East-Europe run, gives rise to fixed costs of about USD 30,000 per day (including capital + interest on loans + crewing and maintenance) and variable costs of about USD 95,000 per day (including bunker costs + canal costs + port costs + insurance + miscellaneous). Hence, an increase in the total round-trip time of, for example, 3 days due to increased congestion/waiting times in the different ports of call increases its operating costs with several tens of thousands of dollars per round-trip.

In order to make up for time lost in port and restore schedule integrity, shipping lines can follow a number of strategies (see also Notteboom, 2006). Firstly, they might have their ships sail at full service speed when steaming from one port to the next. However, such a practice can be extremely costly. Figure 1 depicts the relation between service speed and fuel consumption for four types of container vessels and eight different service speeds. This figure indicates that an increase in service speed with just a couple of knots already results in a dramatic increase of fuel consumption. For example, increasing service speed from 22 to 26 knots for an 8,000 teu container vessel increases its fuel consumption by as much as 100 tons per day. With current bunker prices of about USD 300 per ton, this translates into a daily cost increase of USD 30,000 for each of the vessels deployed. For a 10,000 teu ship, which will most probably become the workhorse on the Far East-Europe trade route by 2010, the daily cost increase per vessel would even amount to USD 36,000.

As a matter of fact, bunker prices have nowadays reached such a level that, at least for certain trade routes, it might be justified to add an extra vessel to an existing loop in order to slow down the sailing speed of all vessels plying it, while still maintaining the service frequency (usually weekly). As a case in point, both the Grand Alliance and CMA CGM each decided to add a ninth vessel to one of their respective Asia/Europe loops during the Summer of 2006. The resulting fuel cost savings generated by each of the other eight vessels more than compensated for the cost of hiring and operating the ninth vessel.

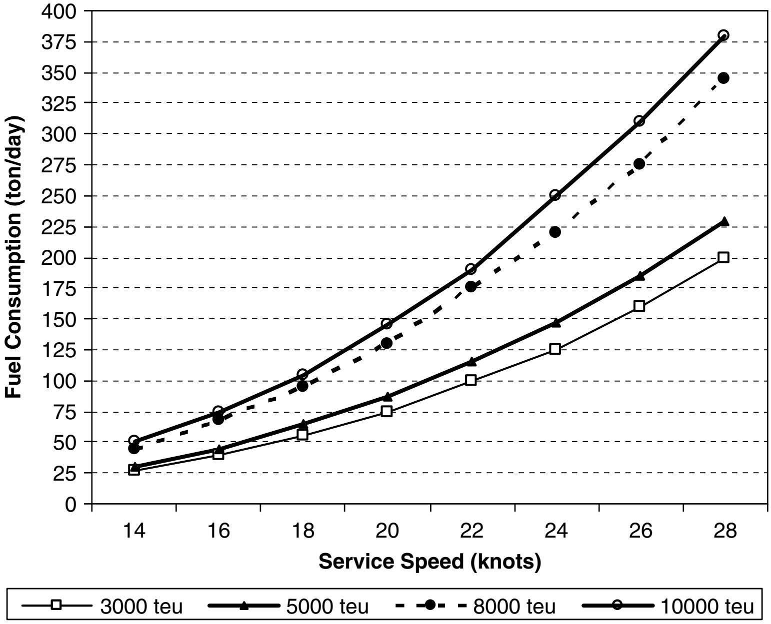

Figure 1: Daily fuel consumption for four types of container ships at different service speeds.
Source: Own representation based on AXS-Alphaliner data.

Secondly, rising port congestion levels might incite shipping lines to reshuffle the order of ports of call on a certain loop (possibly resulting in peak volumes in the 'new' first port of call) or, in extreme cases, leave them with no other option than to omit certain port calls altogether to get vessels back on schedule (cf. the diversions of container ships from Rotterdam to Antwerp and Amsterdam following IT-problems at the ECT Delta terminal on the Maasvlakte in May 2006). As discussed by Notteboom (2006), yet another option to keep deteriorating schedule reliability under control is the so-called 'cut and run' principle, implying that crane operations on a vessel are abruptly stopped even if there are still some containers on the stack waiting to be loaded.

Finally, as noted by Dynamar (2005), the prospect of ever-decreasing schedule reliability constitutes an important reason why shipping lines increasingly seek control of container terminals in strategic locations. Indeed, by investing in (semi-)dedicated facilities, shipping lines can reduce waiting times (cf. berthing on arrival) and are guaranteed of high vessel productivity. Moreover, terminal agreements typically lead to lower handling rates, enabling shipping lines to operate below the normal THC levels. The trend towards more carrier involvement in terminals has not escaped the European port scene, quite to the contrary. Nowadays, quite a number of container terminals in North and South Europe feature a shipping line among their shareholders (in most cases as a minority shareholder). In particular MSC and CMA CGM, the world's second and third biggest container shipping lines, appear to be very active in this field. The same goes for AP Moller-Maersk, Maersk Line's parent company, which operates a large number of container terminals in Europe (and abroad) through its subsidiary APM Terminals.

Terminal operators, especially in those ports that are non-first port of call, are confronted with rising uncertainty with respect to estimated times of arrival (ETA) of container vessels. A container ship missing its contractually negotiated berthing window affects both berth planning and yard planning at seaport terminals. Moreover, as stated above, unexpected delays might force shipping lines to make last-minute changes to their shipping schedules (eg an inversion of port calls or the omission of a certain port call altogether). As a result, terminal operators can face sudden and unplanned peaks in volumes (forcing them to hire extra manpower), possibly leading to domino effects for ships berthing at the same terminal, aggravating problems even more. By way of illustration, the average reliability of vessel arrivals for the container terminals operated by PSA HNN in the port of Antwerp was around 30% in 2005 (based on the monitoring of 30 loops, with somewhat higher reliability levels for deep sea vessels than for feeder vessels). This figure is well below the schedule reliability needed for efficient terminal planning, which can be estimated at

90% (Notteboom, 2006), although this should be considered a theoretical figure.

Inland transport operators are confronted with increasing unreliability of sailing schedules. Inland barge operators, for example, have to take into account the fact that most terminal operators treat deep sea traffic with priority over barge traffic. As a result, securing berthing space becomes ever more difficult for inland barge operators when the reliability of deep sea services decreases. As an example, in the 2004 peak season, barge and feeder operators experienced delays of up to 60 hours at deep sea terminals in Rotterdam and Antwerp, causing havoc in their sailing schedules and forcing them to impose congestion surcharges on their clients to recover costs. In general, inland transport operators (be it truck, rail or barge operators) being faced with increasing delays can see their productivity levels significantly reduced. As nowadays competition is no longer a question of 'port *versus* port' but rather 'supply chain *versus* supply chain', this can obviously have a profound impact on the competitive position of a seaport *vis-à-vis* its nearest rivals. In this respect, it comes as no surprise to see that terminal operators are showing an increasing interest to cooperate on a strategic basis with other players in the supply chain in order to safeguard the integrity of goods flows.

Shippers/consignees, finally, are confronted with an increase in logistical costs because (1) they are faced with decreasing reliability of lead times, obliging them to invest in higher inventory levels in order to avoid disruptions to their production processes and meet service level agreements and (2) they are faced with the so-called 'congestion surcharges' imposed by deep sea shipping lines or inland transport operators aiming to recover the costs associated with rising congestion levels (for a detailed overview of rate and surcharge developments imposed by deep sea shipping lines during 2004–2006, see Drewry Shipping Consultants, 2006c or Dynamar, 2006). The impact of schedule unreliability on shippers/consignees is investigated in more detail in the next section.

THE IMPACT OF DECREASING SCHEDULE RELIABILITY ON SHIPPERS/ CONSIGNEES

The schedule reliability survey performed by Drewry clearly indicates that a large part of today's liner shipping industry still is not able to fulfil customers' ever-increasing needs for supply chain velocity and close adherence to defined lead times. Hence, Drewry regards its survey as an attempt to help shippers plan their supply chains with realistic expectations of delivery times and assist them in the selection of liner carriers, in order to protect the integrity of their supply chains. In this respect, this section presents a case study, based on real-life data, to illustrate the impact of liner schedule unreliability on shippers/consignees.

We consider the case of a multinational manufacturer situated about 35 kilometres from the port of Port Elizabeth in South Africa. The company relies on this port to source a number of crucial components from São Paulo (Brazil) for its production process. In the period June 2005–March 2006, the vessels sailing between Santos (ie the port of São Paulo) and port Elizabeth discharged an average of 638 teu for the company considered during their berthing window from Sunday 0600 to Monday 0600. However, call sizes showed significant variations, ranging from 174 teu (beginning of 2006) to no less than 1,227 teu (mid-June 2005). On average, the company evacuates 56 teu per day from Port Elizabeth to support its production process. Daily evacuation plans are sent to a third-party logistics service provider 12 hours prior to collection. On Mondays and Fridays, the parties hold a meeting to assess the alignment of shipping and evacuation schedules against the company's production schedule.

The sailing distance between the ports of Santos and Port Elizabeth amounts to 4,000 nautical miles or approximately 7,400 kilometres. Under good weather conditions, this distance can be covered in 7 days, implying an average vessel speed of 24 knots. However, the reliability of transit times between Santos and Port Elizabeth is affected in a number of ways. Firstly, vessels sailing from Santos to Port Elizabeth sometimes call at the port of Cape Town first to load and unload containers. This means that Port Elizabeth is not always the first port of call for vessels on this route, making the actual times of arrival of container vessels in Port Elizabeth dependent on possible delays in Cape Town. Secondly, as a result of strong winds and rough seas, vessel delays around Cape Town (which is often referred to as 'The Cape of Storms') are no exception. In the past, situations with up to five container vessels being delayed for days while waiting for the weather to improve were no exception. Thirdly, the ports of Cape Town and Port Elizabeth have in the past been closed on a number of occasions due to employee strikes, adding further to schedule unreliability.

Having said this, it is obvious that it is not only the sea leg of the supply chain that is a source of variability in the overall lead time. For the manufacturer under consideration, the total lead time starts to count immediately after placing an order for spare parts needed for his production process. From that moment on, time is needed to prepare the order in São Paulo, load the containers onto a truck, move them to the port of Santos and put them onboard the ship destined for Port Elizabeth. The time consumed by these activities is clearly not deterministic. However, due to lack of detailed information on their exact duration, only educated guesses could be made on the time required for order placing and order preparation and the time needed for stuffing and transporting the containers to Santos and load them onboard the vessel (cf. infra). In Port Elizabeth, road hauliers are faced with a number of potential congestion points on the roads between the port and the manufacturer's premises.

Because of confidentiality reasons, no specifications could be obtained on the inventory policy used by the company under consideration. In the following paragraphs, in order to illustrate the impact of schedule reliability, we will calculate the required safety stock to be kept by the manufacturer for different service levels under the current level of schedule integrity, and compare it to the safety stock that should be kept when schedule reliability would change.

Lead time and demand data

In São Paulo, the time required for order preparation, stuffing the containers, transporting them to the port and loading them onboard the vessel is assumed to take on average 3 days (including waiting times), with a variance of 1 day^2. As far as maritime transport between Santos and Port Elizabeth is concerned, a detailed monitoring of 30 sailings between June 2005 and March 2006 revealed that the average sailing time between both ports amounts to 8.1 days with a variance of 1.68 days^2. In Port Elizabeth, the discharge of the container vessel, followed by oncarriage to the manufacturer's premises is assumed to take on average 1 day with a variance of 0.5 days^2.

Hence, the average total lead time between the placement of an order and the arrival of the goods at the manufacturer amounts to $(3+8.1+1)=12.1$ days. As far as the lead time variance is concerned, it is assumed that the different components of the total lead time are independent of each other. Under this assumption, the total variance is equal to the sum of the variances of the individual lead time components. Hence, for this specific case study, the total lead time variance amounts to $(1+1.68+0.5)=3.18$ days^2. As far as daily demand is concerned, it was found that (over the period under consideration) it ranged between 51 container loads per day (August 2005) and 60 containers per day (November and December 2005), with an average value of 56 and a variance of 15.51.

Calculating the required level of safety stock

As illustrated above, the supply chain of the manufacturer is characterised by two sources of uncertainty, that is, uncertain lead time and uncertain daily demand. Under such circumstances, the manufacturer should hold some amount of safety stock to protect against stockouts. Broadly speaking, the literature distinguishes between three approaches for setting safety stocks in a stochastic inventory control system, namely the 'Time Supply' approach, the 'Shortage Costing' approach and the 'Service Level' approach (Silver *et al*, 1998). Under the first approach, the safety stock for an inventory item is set equal to a certain time of supply. For example, the inventory item is reordered when its inventory position minus the forecasted lead time demand drops to or below a 2-month supply. Under the second approach, the total of shortage cost and carrying cost is minimised, resulting in a certain amount of safety stock for the inventory item under consideration. Hence, expressing a shortage in monetary terms is an essential element in this approach. Yet, practitioners usually find it hard to determine directly how high shortage costs are, as this involves monetarising qualitative aspects of service such as, for example, loss of goodwill from customers. This problem is bypassed in the Service Level approach, where the objective is to minimise the carrying cost subject to satisfying routinely from stock a certain pre-specified percentage of demand.

Because it is, in principle, always possible to determine the service level that gives the same safety stock as a certain shortage cost and the other way around, service levels are a common point of departure for practitioners and academics. Three different ways exist to express service levels: the carrying costs of an inventory item can either be minimised subject to (i) satisfying a specified probability of no stockout per replenishment cycle (S1), (ii) a specified fraction of demand to be satisfied from stock on hand (fill rate) (S2) or (iii) a fraction of time with positive stock on hand (ready rate) (S3). The S1 service measure is by far the easiest to compute and will be used in the present case study to calculate the level of safety stock required by the manufacturer under consideration. Note that the use of the S1 service measure should be avoided when comparing sourcing strategies with different order volumes (Dullaert *et al*, 2006).

A second factor determining the required level of safety stock (apart from the shortage cost or service level) is the statistical distribution of demand during lead time (DDLT). This refers to the consumption of inventory between the moment an order is placed by the receiver and the moment at which the goods actually arrive. Under the assumptions that DDLT is Normally distributed[3] and that the shortage criterion is to keep the probability of a stock-out during any lead time period below a specified value p, the level of safety stock can be calculated as follows (see also Silver *et al*, 1998):

$$SS = K \times \sigma \tag{1}$$

where SS is the level safety stock, K is the so-called safety factor, that is, the value such that the area under the standard normal curve to the right of K is equal to p (defined above) and σ is the standard deviation of DDLT. Figure 2 depicts the probability distribution of DDLT, its expected value (EDDLT) and the reorder point, defined as EDDLT + SS. If the manufacturer places an order when the inventory level is equal to the average inventory consumption during the lead time, then – by the definition of the expected value – he has a 50%

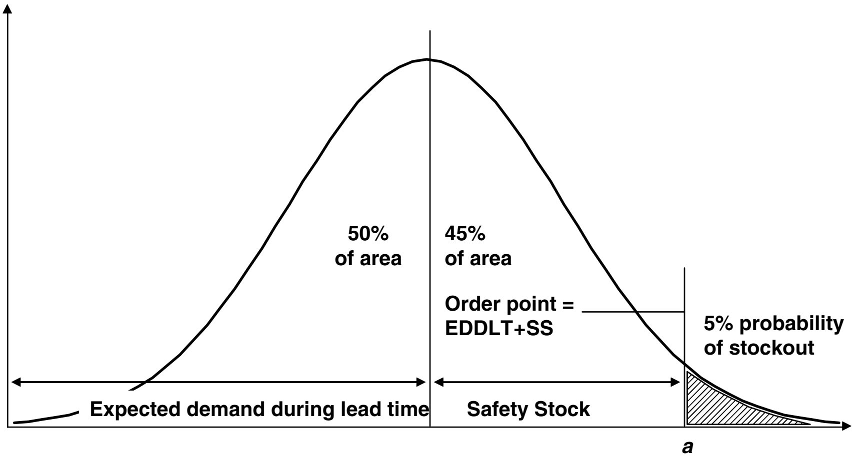

Figure 2: Safety stock for a 95% service level and a Normally distributed DDLT.
Source: Based on Waller (2003).

probability of experiencing a demand larger than EDDLT, resulting in a stockout. However, a 50% stockout risk is of course unacceptable and therefore some amount of safety stock has to be maintained. The risk of having a DDLT that is larger than a in the graph is equal to the probability mass to the right of a, in case 5%. In other words, if we want to reduce the risk of a stock-out to 5%, we should identify the value of a. For a standardised normal distribution, this information can be easily obtained from tables or by using the NORMSINV function in MS-EXCEL.

Under the assumption of a normally distributed DDLT, the value of the safety factor K corresponding to a stockout risk of 5% (ie 95% service level) amounts to 1.64. In other words, to provide a 95% service level, a safety stock of 1.64 times the standard deviation of DDLT should be held. A service level of 97.5% implies a value of the safety factor of 1.96, whereas for a service level of 99.5% (ie a stockout is accepted in just five out of one thousand deliveries) it amounts to 2.58.

If lead time is independent of demand[4] and demand itself is not autocorrelated,[5] the standard deviation of DDLT can be computed as follows:[6]

$$\sigma = \sqrt{(L \times \sigma_D^2) + (D^2 \times \sigma_L^2)} \qquad (2)$$

where L refers to the average lead time, σ_L^2 is the variance of lead time, D refers to the average demand and σ_D^2 is the variance of demand.

Hence, for the present case study, the required level of safety stock can be easily obtained by substituting the lead time and demand parameters into

Table 4: Lead time and demand data, safety factor (*K*) and required level of safety stock (*SS*) for different service levels and different scenarios

	Scenario 1 (current)	Scenario 2 (reliable)	Scenario 3 (unreliable)
L	12.1	11.6	12.6
σ_L^2	3.18	2	3.5
D	56	56	56
σ_D^2	15.51	15.51	15.51
σ	100.80	80.32	105.69
K (95%)	1.64	1.64	1.64
SS (95%)	165.31	131.73	173.34
K (97.5%)	1.96	1.96	1.96
SS (97.5%)	197.56	157.43	207.16
K (99.5%)	2.58	2.58	2.58
SS (99.5%)	260.06	207.24	272.69

Source: Own calculations

equation 2 and choosing the value of the safety factor corresponding to the service level required by the manufacturer. The results are presented in Table 4, in the 'Scenario 1' column. This column indicates that the standard deviation of DDLT amounts to 100.80 container loads. The manufacturer should hold a level of safety stock ranging between 165.31 container loads (for a 95% service level) and 260.06 container loads (for a 99.5% service level). Compared to the average daily demand of 56 container loads, this translates into a safety stock level of about three days and four and a half days of production, respectively.

Calculating the impact of changes in the reliability of the liner schedules

As discussed above, the distance between Santos and Port Elizabeth amounts to 4,000 nautical miles or roughly 7,400 km. At an average vessel speed of 24 knots, this distance can be covered in just 7 days. We will now suppose that, through a combination of operational remedies, the shipping line sailing between Santos and Port Elizabeth is able to substantially increase the transit time performance between the two ports. More precisely, suppose that it is able to shave off half a day of the average transit time (from 8.1 days to 7.6 days), while transit time variability is reduced from 1.68 days^2 to 0.5 days^2. This results in a total lead time of $(3+7.6+1)=11.6$ days with a variance of $(1+0.5+0.5)=2$ days^2. The effects on the manufacturer's safety stock are presented in the 'Scenario 2' column in Table 4. This column indicates that, due to the shorter and more reliable transit time at sea, the standard deviation of DDLT decreases by more than 20% (from 100.80 tons to 80.32 tons), resulting in a similar decrease in the required level of safety stock for each of the three service levels. For example, whereas under current circumstances a safety stock of 197.56 container loads should be kept in order to guarantee a 97.5% service level, it can be reduced to 157.43 container loads when schedule reliability is improved.

It goes without saying that the 20% reduction in the safety stock level can yield significant cost savings for the company under consideration. Even for spare parts with a relatively low value (eg EUR 20,000 per container load) and holding costs of, say, 30% per year (including interest, depreciation, insurance and warehousing costs), a reduction in the required safety stock of 40.13 container loads results in annual cost savings of EUR 240,780. For high-value spare parts (eg EUR 100,000 per container load) being subject to high holding costs (eg 50% per year, as a result of high depreciation and high insurance costs), the resulting cost savings would amount to a substantial EUR 2 million on an annual basis.

The impact of increasing schedule reliability can also be looked upon in another way. If the manufacturer retains the same level of safety stock even after improved schedule integrity, the service level will increase. For example, a safety stock level of 165.31 container loads would, with improved schedule reliability, yield a value of the safety factor K of 2.058, corresponding with a service level of more than 98% instead of just 95%. Similarly, if the manufacturer decides to keep a safety stock of 260.06 container loads even after improved schedule integrity, the resulting safety factor of 3.237 would imply a service level of more than 99.9%. Under such circumstances, the manufacturer would be exposed to a stockout in less than one out of one thousand deliveries.

The final column of Table 4 ('Scenario 3') depicts a situation in which the liner schedule reliability *decreases* further from its current level. More specifically, the transit time between Santos and Port Elizabeth takes on average 8.6 days instead of 8.1 while the variance increases from 1.68 days^2 to 2 days^2. This results in a total lead time of 12.6 days with a variance of 3.5 days^2. Under such circumstances, the standard deviation of DDLT increases from 100.80 to 105.69 tons, resulting in a 5% increase in the required level of safety stock for the three service levels under consideration.

CONCLUSIONS AND AVENUES FOR FURTHER RESEARCH

Organisations involved in global sourcing are faced with variability in lead times. The length of the supply chain, both in terms of distance and the number of parties/links involved, makes it virtually impossible to guarantee an overall deterministic lead time. Although shipping companies advertise liner services with a limited time variability through fixed-day weekly schedules, in reality, the schedule reliability on worldwide liner services is found to be relatively low, with significant differences between shipping lines and trade routes. This can be explained by a number of factors, many of which are beyond shipping lines' control. A major factor contributing to decreasing schedule integrity in recent years is the mismatch between demand for container services and the supply of container handling capacity. Inspired by the strong growth in container traffic in recent years and anticipating on future volume increases, many shipping lines have invested heavily in upgrading their containership fleets. This is in stark contrast with the delays (or even cancellations) experienced in the development of additional container handling capacity at terminals around the world. This mismatch between supply and demand for container services has caused increasing terminal utilisation levels, causing severe congestion problems during peak periods.

Decreasing liner schedule reliability affects several actors throughout the supply chain. For a shipping line, the delays in ports add to the duration of the total round-trip time, affecting bottom-line profits through additional fixed daily ship costs and/or increased operational costs by the need to sail at full service speed to make up for lost time. While shipping lines indeed have a number of options to restore schedule integrity, these options come at a (large) cost. Secondly, decreasing schedule integrity influences the reliability of expected times of arrival (ETA) of ships at seaport terminals, confronting the terminal operator with both berth planning and yard planning problems. Low schedule reliability does not only limit efficient terminal planning, it also exposes inland transport operators to increasing delays and reduced productivity levels. In the present paper, however, the main focus was on the increasing costs incurred by shippers/consignees due to schedule unreliability. Apart from an increase in 'out-of-pocket' costs (due to the imposition of congestion surcharges by deep sea shipping lines or inland transport operators), shippers/consignees are also confronted with an increase in logistical costs due to the requirement to invest in higher inventory levels in order to avoid disruptions to production processes and meet service-level agreements. In the present paper this was illustrated by means of a case study dealing with a manufacturer located in South Africa who sources spare parts from South America. Being faced with two sources of uncertainty (ie lead time uncertainty and demand uncertainty), the manufacturer needs to invest in a certain amount of safety stock to provide protection against stockouts. We compared the safety stock under current schedule reliability levels with the safety stock that should be kept when schedule integrity would change, and found that an improvement in schedule reliability can lead to significant cost savings for the company under consideration.

As one of the main factors influencing schedule reliability in seaports is formed by knock-on effects of delays suffered in previous ports of call, it can be expected that schedule integrity will be higher in those ports that are first port of call for import cargo. Indeed, by modifying sailing speed at sea, shipping lines should be able to more or less accurately maintain the ship's expected time of arrival in the first port of call (factors such as accidents at sea notwithstanding). On the other hand, schedule reliability in a port that is only the fourth or fifth port of call on a certain loop is heavily dependent on time delays experienced in the previous three or four ports. In this respect, the investigation of the relationship between schedule reliability in a given port and its calling position on the different loops by which it is served certainly forms an interesting avenue for further research. The results of this investigation might well provide further backing to the willingness of the Antwerp maritime community to make Antwerp first port of call for import cargo originating from Asia.

Another matter worth investigating is whether there exists a relationship between schedule reliability and the average size of vessels deployed. Given the larger call sizes and higher draught requirements associated with large post-panamax vessels, we expect that increasing vessel sizes lead to decreasing schedule reliability, especially if ports with tidal restrictions are included in the sailing schedules. In view of the massive amount of 5,000+ teu container ships to be delivered over the coming years, this might well result in huge problems for terminal operators in some ports around the world, unless much-needed investments to improve the nautical accessibility can be realised without too much delay.

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ENDNOTES

[1] Drewry (2006a) defines 'on-time' arrival as when the ship arrives at the port of destination on the scheduled day of arrival or on the day immediately before the scheduled day of arrival.

[2] Similar utilisation levels were found by Drewry Shipping Consultants (2005), reporting average utilisation of Northwest European container ports of 86.6% in 2004. The major gateway ports of Rotterdam, Hamburg and Antwerp even experienced utilisation levels of well above 90% that year.

[3] This assumption is often made in logistics applications; however, it has been criticised in the recent literature.

[4] Independence between lead time and demand will characterise most real-life situations. When lead time and demand are not independent, however, the standard deviation of demand during lead

time is equal to $\sqrt{(L^2\times\sigma_D^2)+(D^2\times\sigma_L^2)+\sigma_D\sigma_L}$ where σ_D and σ_L represent the standard deviation of demand and of lead time, respectively (Allen *et al*, 1985).

[5] Autocorrelation measures the extent to which values for a single variable are correlated over time. If demand is autocorrelated, this means that the demand observed in one day depends on the demand in previous days. For a discussion on the effect of autocorrelation on customer service, see Zinn *et al* (1992). See also Ray (1980).

[6] For a similar calculation, using the coefficient of variation instead of the variance, see Gross and Soriano (1969, pp. 68–69). Another way of calculating safety stock, which uses the variance of demand forecast errors instead of the variance of demand, can be found in Zinn and Marmorstein (1990). See also Tyworth (1992).

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