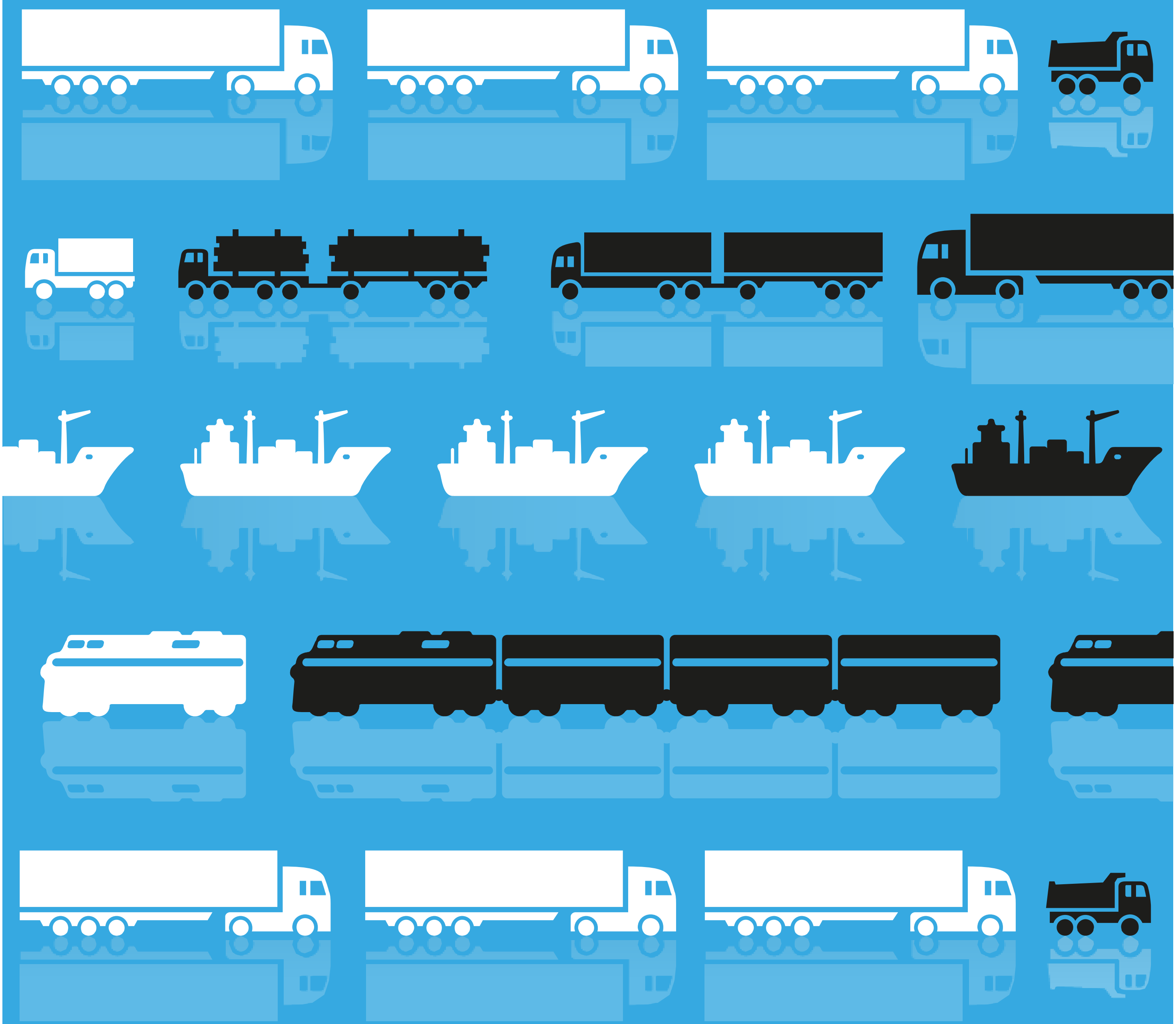

VALUE OF TRANSPORT TIME VARIABILITY FOR FREIGHT TRANSPORT

AUGUST 2013

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Abstract

The Swedish Transport Administration (Trafikverket) uses Cost Benefit Analysis (CBA) extensively when investments are to be made in new road or rail infrastructure. There is a wide spread opinion among representatives of the industry and among many CBA practitioners that measures aimed at improved reliability of freight transports is an area where the current tools for CBA cannot meet the needs. The ultimate aim of our approach is to produce estimates for value of transport time variability (VTTV) that within a short timeframe can be of practical use in CBAs. This report is the first step in a process that explores the costs related to delays of freight transports and where the last step will be the development of estimated costs for delays that The Swedish Transport Administration can use in future CBAs.

The consequences of major delays vary widely between different customers. While delays in passenger traffic are usually measured in minutes, demands regarding freight traffic vary from minutes up to several days. Freight transport involves a multitude of shipments of different sizes, characteristics and requirements.

In this report, possible effects arising from delays in freight transport are identified and categorized. Effects have been divided into logistics effects (arising at links or nodes), business effects and system effects. The different costs related to these effects can be condensed into five key factors:

1. Standardised delay costs
2. Length of delay in time
3. Size of shipment in tonnes
4. Type of goods
5. Vehicle type

Most of identified the costs are judged to be possible, and feasible, to estimate in the current model, and some of them not. A structure assigning different costs to different parts of a transport relation is presented. This makes it possible to calculate the delay effects of a transport chain by summing up the different variables. The structure also defines the boundaries for what to include in VTTV by introducing the scope of variables, range of costs, and scale of effects.

Even if the method should include as many aspects of freight transport practice as possible, effort has been put into creating a solid theoretical ground to base it on. The theoretical framework presented here provides a basis for further development of CBA for freight transport, not only concerning variability of the transport time. A method for estimating VTTV is derived. The proposed method is basically a cost-savings approach. Two distinguishing features of freight transports is that (1) several actors are influenced by a change in transport time variability or other attributes of transports, and (2) a freight transport is an intermediate product. This may double count costs related to VTTV but also that important costs get excluded from the estimation. To address this question a microeconomic derivation, from profit maximization, is performed of cost functions for sending and re-

ceiving firms together with the carrier (transport company). The derivation shows that it is necessary to use a non-standard form for the cost functions of the actors. The most notable difference is that transport price should be excluded from the cost functions. The combined VTTV for the three actors is derived as a sum of the derivative of their cost functions with respect to transport time variability. It is shown that the obtained VTTV is a sum of two distinct effects, (1) changes in the time-dependency of the expected cost, and (2) changes in the probability distribution of transport time.

Furthermore, a preliminary test for collecting data for the future estimation of VVTV is presented, which indicates that data exists but that a full-scale data collection will meet challenges. An alternative method for estimating operative train transport costs due to delays, using model calculations, is presented. An analysis of major traffic interruptions in the railway's freight traffic between 2000 and 2013 is made and is concluded that an average of 2.5 interruptions a year lasted 5 days and affected approximately 50 freight trains. These interruptions appear to have increased in particular after 2005, mainly for two reasons: derailments and extreme weather conditions. Derailments have increased as a consequence of increased traffic and thereby increased wear and backlogged maintenance. The extreme weather conditions have increased due to the climate crisis.

Even when new transport time variability values have been calculated, methods for estimating the effect of different infrastructure measures on the variability of the transport time need to be developed before complete CBAs for freight transport, regarding also the reliability of the transport system, can be carried out.

Sammanfattning på svenska

Introduktion

Samhällsekonomiska kalkyler används i stor utsträckning av Trafikverket när beslutsunderlag till åtgärder i infrastrukturen ska tas fram. Den finns en utbredd uppfattning bland representanter för svensk industri och många samhällsekonomer att åtgärder med syfte att förbättra tillförlitligheten hos godstransporter är ett av områdena där de samhällsekonomiska kalkylerna behöver utvecklas.

Denna rapport är det första steget i en process som undersöker kostnaderna som orsakas av förseningar av godstransporter. Det sista steget kommer att vara framtagandet av kostnadsvärderingar för förseningar, som Trafikverket kan använda i framtida kalkyler. De områden som gynnas av bättre förseningsvärderingar är främst kalkyler för

- Operativa åtgärder, underhåll och reinvesteringar
- Åtgärder för högre beredskap (för exempelvis snö)
- Olika typer av åtgärder för att förbättra systemets robusthet (till exempel bättre omledningsmöjligheter)

För att kunna genomföra dessa typer av kalkyler behövs kunskap om bland annat hur stora kostnaderna blir när störningar och förseningar av olika magnitud inträffar. Till en komplett samhällsekonomisk kalkyl för en viss åtgärd behövs vanligtvis mer information. För att exempelvis bestämma det samhällsekonomiska värdet av förbättrat underhåll av järnvägen, behöver man veta:

- hur satsningen påverkar järnvägens standard,
- hur järnvägens standard påverkar antalet infrastrukturfel,
- hur felen påverkar tågförseningar,
- hur tågförseningar påverkar användarna.

Detta projekt fokuserar på den sista delen i denna kedja – sambandet mellan storlek och frekvens av störningar och de resulterande kostnaderna, och i slutänden värdet för Sveriges ekonomi av minskade förseningar.

Projektets mål har varit att utveckla en metod för att uppskatta *VTTV* – Value of Transport Time Variability (värdet av transporttidens variation) för godstransporter. I denna rapport presenteras ett förslag på metod. För att erhålla en uppsättning värden färdiga att använda i samhällsekonomiska kalkyler enligt den föreslagna metoden, är nästa steg en omfattande insamling av data som beskrivs i rapporten, samt själva estimeringen enligt den matematiska modell som presenteras här. En andra målsättning med projektet har varit att öka den generella kunskapsnivån om VTTV för svenska förhållanden.

Projektplanen och konstellationen för projektet skapades i en förstudie[1] om VTTV 2012, som utfördes av WSP och finansierades av Vinnova. Konstellationen utgörs av en arbetsgrupp och en referensgrupp. Göteborgs Universitet, KTH, Transrail, Vectura och WSP har deltagit i arbetsgruppen och författat denna rapport. Referensgruppen består av logistikchefer på olika transportköpande företag, representanter för transport- och speditionsföretag, Trafikverket, intresseorganisationer och andra godstransportexperter.

Rapporten består bland annat av en beskrivning av vår referensram sett till transport- och logistiksystem, transporttidsvariation i samhällsekonomiska kalkyler och tidigare relevanta studier. Därefter presenteras en framtagen struktur för att hantera och sortera identifierade effekter och relaterade kostnader till följd av godstransportförseningar. En mikroekonomisk modell som utvecklats som teoretisk bas för estimeringen av VTTV beskrivs och beräkningarna härleds matematiskt. Slutligen presenteras metoden för och resultatet av ett litet, preliminärt test för att samla in nödvändig data som utförts inom ramen för projektet, en undersökning och analys som gjorts av större tågtrafikstörningar och dess effekter i Sverige sedan 2000 samt en inom projektet framtagen metod för att modelluppskatta operativa kostnader för tågtransporter till följd av förseningar, som kan användas som alternativ till att samla in data manuellt.

Referensram

Godstransporter innefattar en mångfald av sändningar av olika storlek, karaktär och behov. Effekterna av en försening beror i hög utsträckning på sammanhanget. En timmes försening av en skruv kan kosta miljoner i ett visst sammanhang, medan en hel fartygslast skruvar i ett annat sammanhang kan bli ett dygn försenat med försumbara konsekvenser.

Transport- och logistiksystem som ligger till grund för godstransporter är komplexa, med olika transportslag inblandande och beroendeförhållande mellan säljare, köpare, speditörer etc. samt hur transporterna hänger ihop med den interna logistiken på olika företag. Transportnätverk kan beskrivas med hjälp av noder och länkar i olika med varandra sammankopplade nät. Noderna motsvarar terminaler, cross-docking-stationer, butiker och andra platser där gods hanteras eller lagras. Länkarna motsvarar vägar, järnvägar, vattenvägar eller luftvägar.

Den genomförda litteraturstudien visar att i princip alla genomgångar på ämnet VTTV för godstransporter har kommit till slutsatsen att VTTV är en viktig faktor att ta med i samhällsekonomiska kalkyler relaterade till godstransporter – ingen studie har kommit fram till att VTTV är försumbart. Däremot finns ingen konsen-

[1] Se rapport *Järnvägsnätet och godstrafikens behov – underlag för projektansökan,* WSP Analys & Strategi, 2012-03-30

sus om dimensioner och enheter för VTTV, eller för dess storleksordning. En viktig faktor för de divergerande resultaten kan vara den stora mängd olika mått på transporttidsvariation som använts i olika studier, såsom andelen försenade transporter, den förväntade förseningen, etc. Ett naturligt mått skulle kunna vara transporttidens standardavvikelse.

Den metod som nästan uteslutande använts i studier på VTTV är SP-metoden, till skillnad från t.ex. studier på värdet av den ordinarie transporttiden, där flera olika metoder tillämpats, men resulterat i värden av samma storleksordning.

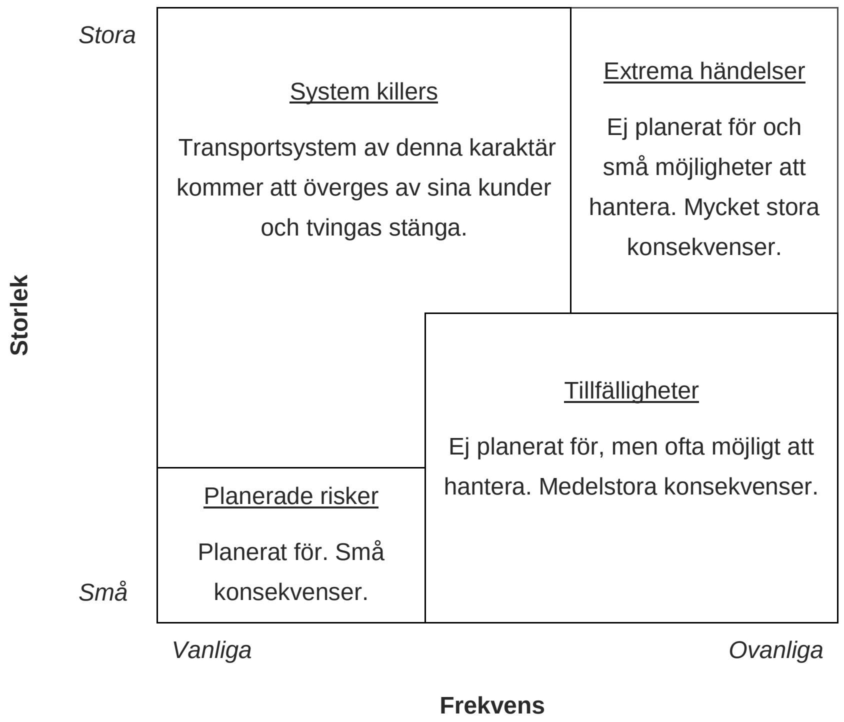
De krav och önskemål transportköpande företag har på transporterna är välkända och flera studier har kommit till samma slutsats. Transportkunderna prioriterar transportkvalitet, tillförlitlighet och transporttid. Dessutom är naturligtvis även kostnaden viktig. Transportkvalitet är ett relativt vagt begrepp som kan innefatta allt relaterat till hur väl transporten utförs. Att ha tillförlitliga transporter, det vill säga att varorna levereras på avtalad tid, är en av de viktigaste faktorerna och rankas högre än själva transporttiden. Kostnaden för transporten rankas som den allra viktigaste faktorn, men först efter att grundläggande kvalitetskrav är uppfyllda.

En undersökning (Lundberg, 2006) bland cirka 100 svenska industriföretag som sänder varor över olika avstånd och med olika transportslag, har kartlagt bland annat hur ofta sändningar blir försenade samt konsekvenserna av detta. Studien visade bland annat att 9 % av företagen fick extra kostnader direkt när en sändning försenas. Efter 2-8 timmars försening hade ytterligare 45 % av företagen ökade kostnader och efter en respektive 2 dagars försening uppgav 21 respektive 10 % av företagen att extra kostnader uppstod. För långa förseningar verkar kostnader uppstå efter ett jämnt antal 24-timmarscykler.

Transportattribut som påverkas av förseningar

För att kunna förstå effekterna av förseningar, måste man förstå de ingående logistiska och transportprocesserna. En typisk varutransport har ett antal nyckelaktiviteter som kan påverkas av en försening: själva transporten, eventuella omlastningar, leveransen, andra planerade transportuppdrag samt användningen av godset. För var och en av dessa nyckelaktiviteter, kan ett antal faktorer som påverkas av förseningar identifieras, tillsammans med de kostnadsdrivare som resulterar i de sökta kostnaderna. I en transportkedja som består av flera ben, kan en försening som uppstår i en del även sprida sig till de påföljande delarna. De identifierade effekterna kan delas upp mellan de som uppstår i företagens verksamhet och de som uppstår inom själva logistiken. Logistikeffekterna kan i sin tur delas upp på länk- och nodeffekter. Till ytterligare en kategori räknas de effekter som uppkommer tillföljd av hela systemets utformning. Med hjälp av denna uppdelning kan effekter adderas för olika delar av transportkedjan utan att riskera dubbelräkning. I tabellen nedan kategoriseras alla identifierade effekter tillsammans med den aktivitet, kostnad och kostnadsdrivare de är relaterade till. De olika kostnaderna bedöms kunna uppskatttas utifrån någon egenskap hos sändningen, såsom exempelvis fordonstyp eller varuslag. Dessutom anges vilka variabler som behövs för att kunna beräkna kostnaden.

De vanligaste störningarna i transportsystemet är små och eftersom de är vanliga är de förväntade. Det innebär att man ofta har planerat in marginaler i systemet som kan absorbera dessa störningar och konsekvenserna är ofta försumbara. Större störningar är mer ovanliga och är därför inte planerade för i systemet. Detta faktum gör att konsekvenserna blir än större. Olika typer av störningar kan kategoriseras efter storlek och frekvens enligt figuren nedan.



Skadan en störning orsakar, tillsammans med sannolikheten att störningen ska inträffa, ger den risk störningen utgör. De olika typerna av störningar i figuren utgör olika stora risker, vilket kan ge ledning om hur de resulterande kostnaderna ska beräknas. ”System killers” kan ignoreras eftersom de inte kan förekomma i ett hållbart transportsystem. Extrema händelser innebär en liten risk (stora skador men liten sannolikhet), men eftersom händelserna är just extrema och så ovanliga, hanteras de bäst i en separat analys. De planerade riskerna utgör också en liten risk (hög sannolikhet men små skador) och kostnaderna uppskattas bäst genom säkerhetslager och kostnader för backup och flexibilitet. Den största risken kommer från de tillfälligheter som inte är planerade för och som orsakar större skador.

Aktivitet	Kategori	Uppdelning efter	Kostnad	Kostnadsdrivare	Variabel
Transport	**Länkeffekt**	Fordonstyp	Tidsberoende fordonskostnader	Längre transporttid	Fordonskostnader, förseningens längd
			Avståndsberoende fordonskostnader	Längre transportavstånd	Fordonskostnader, extra transportavstånd
			Direkta kostnader för backup och flexibilitet	Omfördela andra resurser för att utföra den planerade transporten	Kostnad för den extra transporten
			Förseningskostnader för andra sändningar	Förseningen orsakar förseningar hos andra planerade sändningar	Transportkedjeeffekter, andra kostnadsdrivare
	Verksamhetseffekt	Varuslag	Kapitalkostnad för godset	Längre transporttid	Varuvärde, sändningsstorlek, förseningens länd
	Systemeffekt	Transportslag	Indirekta kostnader för backup och flexibilitet	Generellt ej tillförlitligt transportsystem	Uppfattad tillförlitlighet, kostnad för backup
Omlastning	**Nodeffekt**	Fordonstyp	Tidsberoende fordonskostnader	Ankomst utanför öppettid eller störning av terminalens operativa planering	Fordonskostnader, förseningens längd
			Kostnader för övertid för terminalpersonal	Ankomst utanför öppettid eller störning av terminalens operativa planering	Personalkostnader, antal övertidstimmar
			Kostnad för lagring på terminal	Missad omlastning	Lagerkostnader på terminal, sändningsstorlek, förseningens längd
	Verksamhetseffekt	Varuslag	Kapitalkostnad för godset	Missad omlastning	Varuvärde, sändningsstorlek, förseningens länd
Leverans	**Nodeffekt**	Fordonstyp	Kostnader för övertid för mottagande personal	Ankomst utanför öppettid eller störning av terminalens operativa planering	Personalkostnader, antal övertidstimmar
			Tidsberoende fordonskostnader	Ankomst utanför öppettid eller störning av terminalens operativa planering	Fordonskostnader, förseningens längd
Användning av godset	**Verksamhetseffekt**	Varuslag	Direkt kostnad för brist på varor	Användning av gods	Näringsgren, varuslag, sändningsstorlek, effekt av brist på varor
			Indirekt kostnad för brist på varor	Användning av gods	Näringsgren, varuslag, sändningsstorlek, effekt av brist på varor
			Kostnad för säkerhetslager	Generellt ej tillförlitligt transportsystem	Uppfattad tillförlitlighet, kostnad för säkerhetslager
Kedjeperspektiv	**Systemeffekter**	Transportslag	Spridningseffekter i kedjan orsakar andra förseningskostnader	För små tidsmarginaler mellan transportkedjans steg	Karaktär och komplexitet hos transportkedjan, andrakostnadsdrivare
			Kapitalkostnad för godset	Generellt ej tillförlitligt transportsystem	Varuvärde, uppfattad tillförlitlighet

Alla dessa faktorer kan inte tas med i beräkningarna. All typ av data är inte tillgänglig för insamling, och värderingarna som tas fram behöver vara konsekventa med resten av modellsystemet som används för att ta fram samhällsekonomiska kalkyler. Störningar av typen ”System killers” och extrema händelser bör inte studeras för att tas med i VTTV-beräkningarna. Vidare föreslås att de faktorer som klassas som systemeffekter i tabellen ovan exkluderas, med undantag för de kostnader som uppstår genom att en försening sprider sig i kedjan. Inte heller de indirekta kostnaderna till följd av förseningar bör tas med, eller kostnader för förseningar som sprider sig till andra planerade transporter.

Sammantaget kan kostnaden av en försening uppskattas utifrån fem faktorer: Standardiserade förseningskostnader, förseningens längd, sändningsstorlek (ton), varuslag samt fordonstyp. Den största utmaningen är att generalisera transportkedjornas karaktär och komplexitet så att data kan samlas in på ett realistiskt sätt.

Beskrivning av mikroekonomisk modell

De samhällsekonomiska analyserna inom transportområdet bygger på den så kallade välfärdsanalysen inom ekonomisk teori. Där behandlas företagen formellt som vinstmaximerare. Att härleda VTTV utifrån vinstmaximering ger en utgångspunkt för hur VTTV kan estimeras utifrån data om företagens enskilda transport och de kostnader som de har genererat. Utöver detta fås också viss information om egenskaper hos VTTV, som till exempel visar hur dubbelräkning av kostnadskomponenter undviks när flera parter har en del VTTV. Detta är fallet för godstransporter eftersom transporter är en del av företagens produktionssystem och på grund av att det normalt finns en vertikal marknadsstruktur inom näringslivet, där ett företags produktion används som insats i ett efterföljande företags produktion.

VTTV kan härledas från de ingående företagens så kallade kostnadsfunktioner. De ger den minsta kostnad som ett företag kan producera en given volym av sin produkt för. Utöver att vara en funktion av produktionsvolymen så är kostnadsfunktionen normalt också en funktion av priser för insatsfaktorer. Om ett företags kostnad påverkas av transportens egenskaper, det så kallade transportattributet, så blir också dess kostnadsfunktion en funktion av transportattributet.

För en vertikal marknadsstruktur där transporter ingår, och flera aktörer kan påverkas när transportattributen för en viss transport ändras så måste vissa av aktörernas kostnadsfunktioner justeras, annars sker dubbelräkning av kostnader. Justeringen innebär att om ett företag använder ett annat företags produktion som insats så ska kostnaden för den produkten strykas ur kostnadsfunktionen till företaget som använder produkten som insats. Den kostnaden representeras av kostnadsfunktionen till företaget som tillverkade produkten. För att det ska ge en korrekt kostnadsfunktion så stryks priset för insatsvaran som variabel men volymen som användes som insats förs in som variabel i kostnadsfunktionen som justeras.

Den minsta tänkbara vertikala marknadsstrukturen där godstransporter ingår består av en transportör och en transportköpare och transporten sker internt inom köparens företag. Kostnadsfunktionen för transportköparen blir då formellt sett en funktion av företagets produktionsvolym och dess transportvolym, priset för varan som produceras, och priset för alla insatsfaktorer förutom transportpriset, samt företagsspecifika attribut och transportattribut. Transportörens kostnadsfunktion är en funktion av transportvolymen, priset för alla insatsfaktorer som är nödvändiga för att producera transporten, samt företagspecifika attribut och transportattribut.

För denna minsta möjliga vertikala marknadsstruktur går det att visa att VTTV är derivatan av de summerade kostnadsfunktionerna med avseende på attributet för transportidens variabilitet, z_v, av de adderade kostnadsfunktionerna för köparen av transporten c^B och transportören c^C, det vill säga

$$VTTV = \frac{\partial c^B}{\partial z_v} + \frac{\partial c^C}{\partial z_v} \tag{1}$$

De två termerna i summan kan tolkas som transportköparens och transportörens del i VTTV. Uttrycket visar också att om en parts kostnader inte påverkas av en förändring i z_v så bidrar inte den parten till VTTV, eftersom dess derivata då blir noll. Förutsättningen för uttrycket (1) är att transportköparens kostnadsfunktion justeras, så som beskrivs ovan, det vill säga att transportkostnaden inte tas med (den representeras av transportörens kostnadsfunktion). Anledningen till detta är att transporten i det här fallet är en mellanliggande (intermediär) tjänst. På samma sätt kan fallet då godssändaren och godsmottagaren är olika företag hanteras. Om vi låter transportköparen vara mottagare så stryks kostnaden för (den intermediära) varan som transporteras ur köparens/mottagarens kostnadsfunktion, och derivatan av sändarens kostnadsfunktion adderas till uttrycket i (1). Om en ändring i transporttidens variabilitet påverkar andra mellanliggande marknader före slutkonsumenten, så kan deras bidrag till VTTV på samma sätt adderas till i (1).

Utgångspunkten för metoden är att estimera kostnadsfunktionerna som en funktion av transportattributen, inkluderat transporttidens variabilitet, och övriga variabler som beskrevs ovan. VTTV fås sedan genom att derivera summan av de relevanta kostnadsfunktionerna med avseende på transporttidens variabilitet. Transporttidens variabilitet är en populationsegenskap för en given typ av transporter, till exempel i en viss transportrelation med ett givet färdmedel. Ett alternativt sätt att estimera kostnadsfunktionernas beroende av transporttidens variabilitet är att först estimera variabiliteten i ett antal relationer samt att beräkna företagens kostnader i samma relationer, sedan utförs en linjärregression med dessa variabler (och övriga variabler som ingår i kostnadsfunktionerna). Detta sätt är dock problematiskt. Mått på variabilitet, till exempel standardavvikelse, har normalt sett höga skattningsvarianser (högre än medelvärden), vilket kräver stora urval för att ge bra resultat. Utgångspunkten är istället att estimera kostnadsfunktionerna för individuella transporter, genom att uppgifter om både tidsavvikelser och kostnader samlas in för enskilda transporter. Sedan aggregeras dessa samband upp till nivån för kostnadsfunktioner. Metoden kan beskrivas som en kombination av kostnadsfunktionsestimering och ”cost savings approach”.

Maximeringsuttrycket i teorin för vinstmaximerande företag har karaktären av en svart låda med en tämligen hög aggregeringsgrad, specifikt så gäller maximeringen är över en given men ospecificerad tidsperiod. Att transporttiden varierar innebär att de vinstmaximerande företagen måste hantera osäkerhet. Därför har de antagits maximera den *förväntade* framtida vinsten över den givna men ospecificerade tidsperioden. För att både aggregeringsproblemet och maximeringen över förväntade vinster (eller snarare minimering av förväntade kostnader i detta fall) ska fungera för de observerade kostnadsdata måste vi anta att data kommer från företag som vinstmaximerar och har rationella förväntningar. Antagandet att de är vinstmaximerar behövs för att säkerställa att kostnader för enskilda transporter adderar upp till kostnader för hela perioden så som krävs för kostnadsfunktionerna. Det sistnämnda antagandet om rationella förväntningar behövs för att kunna jämställa faktiska observerade kostnader med företagens minimering av förväntade framtida kostnader.

Uppgifter om ankomsttider för enskilda transporter behandlas som händelser i kontinuerlig tid. Under tämligen generella antagandet innebär detta att ankomsttider (och när så behövs, även avgångstider) för enskilda transporter kan ses som realisationer av en counting process (”räkneprocesser”). Transportidernas, tiden mellan avgång och ankomst, sannolikhetsfördelningar kan då estimeras med hjälp av så kallade intensitetsmodeller. Kostnader för enskilda transporter blir en funktion av kostnader som har genererats av en räkneprocess – ankomsttider/transporttider. Det finns väletablerade metoder för att estimera sådana utvidgade typer av intensitetsmodell, inkluderande regressionssamband för de variabler och attribut som ingår i kostnadsfunktionerna. På detta sätt estimeras de förväntade kostnadsfunktionerna från maximeringsprocessen beskriven ovan. Intensitetsmodellen parameteriseras så att transporttidens sannolikhetsfördelning blir en funktion av attributet för transporttidens variabilitet (t ex standardavvikelse). På så sätt blir även kostnadsfunktionerna funktioner att transporttidens variabilitet.

VTTV beräknas sedan genom att derivera de estimerade kostnadsfunktionerna med avseende på transporttidens variabilitet. Det deriverade uttrycket visar att VTTV kan skrivas som en summa av två komponenter

$$VTTV = VTTV_L + VTTV_\lambda \ . \tag{2}$$

$VTTV_L$ står för effekter som kommer av att de förväntade kostnader hänger samman med en transport förändras när transporttidens variabilitet förändras, till exempel att övertidsuttaget förändras. Den andra termen $VTTV_{\lambda}$ står för effekter som uppkommer på grund av transporttidens sannolikhetsfördelning förändras när dess variabilitet förändras. Den termen innebär att VTTV inte nödvändigtvis behöver vara noll om inga kostnader förändras när variabiliteten förändras.

Estimeringsmetoden är självfallet mest effektiv på lågnivådata över enskilda transporter tillsammans med de kostnader som de har genererat för företagen. Dock är det inte realistiskt ha samla in en fullständigt datamängd på detta sätt. Metoden kan dock kombinera lågnivådata med aggregerade data.

Datainsamlingstest

Baserat på slutsatserna från avsnittet om transportvariabler, extraherades i projektet en lista på variabler som beskriver effekter av förseningar och relaterade kostnader. Dessa delades in i tre kategorier:

1) Värden att försöka samla in genom enkäter och intervjuer
2) Värden att uppskatta från andra källor, exempelvis ASEK, Samgods eller andra modeller
3) Värden som inte bedöms kunna inkluderas på ett bra sätt i nuläget, möjligtvis i en vidareutveckling

Ett småskaligt test att samla in data för variablerna i kategori 1) utfördes med hjälp av tre transportköpande företag i referensgruppen och vissa av de företag som utför transporterna. De ombads välja ut ett antal typiska transportrelationer och beskriva dem med hjälp av ett formulär som tagits fram för ändamålet. Effekter av förseningar beskrevs baserat på riktiga fall eller uppskattningar i de fall data inte fanns tillgängligt. Det lilla antalet respondenter i testet gör det omöjligt att dra några generella slutsatser om tillgängligheten på data. Bara inom testgruppen var det stora skillnader i vilken typ av information som existerade. I inget av fallen fanns färdig statistik av den efterfrågade typen, men i några fall skulle det vara möjligt att kombinera olika datamängder för att estimera de totala kostnaderna. En framtida fullskalig datainsamling kommer att behöva börja med att noggrant designa själva undersökningen och därefter genomföra ett riktigt pilottest. Alla respondenter kommer inte att kunna bidra med all efterfrågad data, men det verkar inte omöjligt att olika företag kan bidra med olika typer av data och på så sätt komplettera för varandras luckor.

1 Introduction

The Swedish Transport Administration (Trafikverket) uses Cost Benefit Analysis (CBA) extensively when investments are to be made in new road or rail infrastructure. CBA is used both to find the right solution to a specific problem (within the physical planning process) and to determine which projects are good enough to qualify for state-funding (the economic planning process).

The result of the CBA is not the sole determinant when different projects are being ranked, but the CBA does affect the final outcome[2]. It is therefore important that as many as possible of the important effects of a road or rail investments can be included in the CBA – or that there is not a bias that negatively impact certain kinds of infrastructure measures. As important is that we get a better understanding of these effects and the causes and dimensions of them. There is a wide spread opinion among representatives of the industry and among many CBA practitioners that measures aimed at improved reliability of freight transports is an area where such a bias exists.

The ultimate aim of this approach is to produce estimates that within a short timeframe can be of practical use in CBAs. This report is the first step in a process that explores the costs related to delays of freight transports and where the last step will be the development of estimated costs for delays that The Swedish Transport Administration can use in future CBAs. Until this date CBA in transport planning has mostly been used to evaluate investments in infrastructure but efforts are now being made to bring CBA to the area of maintenance. The realm of CBA could be widened even more. The areas that will benefit from better estimations of the cost of delays can be seen if we look upon the sources of delays and the measures that could be undertaken to reduce these risks. Disruptive events occur within all transport sectors but the severity of the delays is often larger within the rail sector.

Primarily there are difficulties in CBA for:

- Operations, maintenance and reinvestments
- Measures for higher preparedness (for e.g. snow)
- Different types of actions in order to enhance the robustness of the system (e.g. re-routing possibilities)

To be able to realize these types of calculations we need knowledge about, among other things, how large the costs are when disruptions and delays of different magnitude occur.

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[2] Eliasson & Lundberg (2011)

There is a large range of measures that can improve the reliability of freight transports and where CBA could be of use. Maintenance of road and rail affects the number of infrastructure errors. Improved drainage of road and rail embankments help reduce the risks in connection to heavy rain and floods. The negative effects of heavy snowfall can be reduced by either increased preparedness for snow clearance or investments in equipment that melts the snow, building roofs above sensitive areas etc. Trees close to road or rail can be cut down. Within the rail sector automatic detectors could be installed to reduce the risk of malfunctioning vehicles damaging the rail. “Overcapacity” can allow trucks and trains to change their route when accidents occur etc.

Currently delays of freight-transport are often excluded in CBAs for infrastructure investments. The reason is sometimes that it is difficult to quantify how much the delays would be reduced if a certain measure was undertaken, but often it is excluded because the impact upon the CBA-results would be barely noticeable – even if it was included. One reason is that today the costs of delays are only calculated based on the value of the goods that is transported. It does not include any component that shows how the cost of transport changes when things do not turn out according to plan. Neither does it include lost sales or harmed customer relations. Before we explain how the costs of delays are valued, it is time to introduce some definitions.

The Value of Transport Time Savings (VTTS) gives the valuation of a decrease (though they are used for increases as well) in the *expected* transport time of a transport. VTTS depends upon the value of the goods being transported and the interest-rate that is used. If the goods are in route for 1 hour longer it means that the sale of the goods is delayed with 1 hour. The cost of this is the interest-rate times the value of the goods. The costs of transports, per hour and per km, are calculated separately.

The Value of Transport Time Variability (VTTV) gives the valuation of a change in the variation around the expected transport time. VTTV can be made up of a number of different components and this report will describe which these components should be, how they relate to each other and how they could be calculated. In Sweden, however, the VTTV-value that is currently used in CBA is simply VTTS * 2. The factor 2 was introduced as a compromise in lack of better information, derived from a comparison of values used by several European countries.

This report is about the valuation of changed delays in the transport of goods on the Swedish infrastructure network and ultimately to evaluate the effects on Swedish National Economy.

The methods to quantify how the risks and the size of different delays are effected by different measure also needs improvements, but these are not a part of this project and report.

In this report we focus upon the relationship between the size and frequency of delays and the resulting costs. To make a complete CBA of an infrastructure investment more information is usually needed. For example, to find the socio-economic value of increased maintenance of the railway, we would also need to know:

- how increased spending affects the standard of the railway
- how the standard of the railway affects the number of infrastructure errors
- how the errors affect train-delays
- how the train-delays affect the end users

We focus upon the last step in this chain of events and other projects deal with the other cause-effect relationships.

A key method in the current Swedish transport planning is the Samgods model. The main purpose of the Samgods model is to provide freight transport forecasts to be used as input to CBA and other analyses when taking decisions about future investments in infrastructure. After further development of the Samgods model, the output of the model could be completed with forecasts of the frequency and magnitude of delays. Thus the model could potentially be used to calculate the impact of different infrastructure measures on delays in the freight transport system.

Therefore, the framework of the Samgods model has been considered when designing the structure of the valuation of these delays. Currently, there are no values in the Samgods model regarding the effects of delays. However, there is a structure of different values regarding e.g. costs for vehicles, transhipments, storage, loading/unloading, etc. The values of VTTV are proposed to be estimated so that it matches the commodity-groups used by Samgods and when collecting data for valuation of VTTV the classifications of vehicles etc. should be matched with the Samgods structure.

1.1 Aim and purpose

The aim of this project has been to develop a method for estimating VTTV. The method proposed in this report includes a micro-economic model describing the cost functions for actors involved in freight transport, as well as a structure for collecting data needed to estimate values for using the model. Furthermore, a test has been made to collect data for a few transport relations. This project is the first stage in the process to estimate VTTV. The next stages will include a full-scale data collection (possibly starting by a pilot test) and the actual estimations. A secondary aim of the project is to improve the general level of knowledge on the subject of VTTV for Swedish conditions.

The project plan and constellation was built up within a pre-study[3] on VTTV in 2012, carried out by WSP and funded by Vinnova. The constellation in the current project consists of a work group and a reference group. KTH Royal Institute of Technology, Transrail, University of Gothenburg, Vectura and WSP have participated in the work group. The reference group has representatives from logistics managers at transport buying companies, transportation and forwarding businesses, the Swedish Transport Administration, interest organisations and other freight transport experts. During the project, two reference group meetings have been held where methodological ideas have been presented to the reference group and the group's input has been collected. The aim has been to connect the theory to practice as much as possible, in order to get values that reflect the reality to a further extent than today's values. The reference group has also contributed by providing information on a few transport relations for the test of the data collection structure.

A literature study has been carried out in order to relate the method to previous attempts to estimate VTTV and to choose the best way forward. Even if the method should include as many aspects of freight transport practice as possible, effort has been put into creating a solid theoretical ground to base it on.

A micro-economic model has been developed, describing a transport buying and a transporting company, and how their costs depend on aspects connected to the transport. The model will prevent that the same costs are taken into account twice. The model allocates the different effects of delays, and the related costs, to the companies involved. The model can be applied to all kinds of transport relations, which is necessary because of the high complexity and heterogeneity of the freight transport market. The model is not only valid for the estimation of VTTV, but can also be used in future estimations of other costs related to freight transport.

Different costs caused by variation of the transport time have been identified. Some of them can be modelled and thus included in the estimations, others are excluded for now but could be included in the future as a result of further research, but some effects are judged to be too difficult to model.

Starting from the effects that could currently be included, a structure for collecting data has been created. This structure includes values of resources needed to handle delays of varying magnitude. General data on the transport relations studied also need to be collected (type of goods, number of transhipments, mode of transport, shipment size, etc.). These attributes are crucial to be able to model at least parts of the complexity of the entire freight transport market.

A test has been carried out for three transport buying companies in the reference group, and the transporting companies handling their goods. The purpose was to

[3] See report *Järnvägsnätet och godstrafikens behov – underlag för projektansökan,* WSP Analys & Strategi, 2012-03-30

get a preliminary image of whether the type of data needed is available or not. It is important to point out that this test is *not* a pilot test for a full-scale data collection and a following test estimation of VTTV, since this would require a much larger number of transport relations and a more developed method for gathering the information.

The project has been carried out during the first half of 2013 and is funded by Vinnova, the Swedish Transport Administration and the Confederation of Swedish Enterprise.

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1.2 Acronyms used

The following acronyms are used throughout the report.

CBA = cost benefit analysis

VTTS = the value of freight transportation time savings

VTTV = the value of freight transportation time variability

HEATCO = Harmonised European Approaches for Transport Costing

SP = stated preferences

RP = revealed preferences

JIT = just-in-time

n/a = not applicable

ett = expected transport time

ULD = unit load device

1.3 Disposition

After this introduction, the report starts by describing our frame of reference in terms of transportation and logistics systems, CBA related to transport time variability and relevant previous studies. The following chapter, “Transport attributes influenced by delays", presents a structure for handling and sorting different effects and related costs of delays in freight transport. This is necessary for collecting data to estimate VTTV,

In chapter 4, the theoretical basis for the calculation, the micro-economic model, is described. The estimation of VTTV is derived mathematically.

The next chapter briefly described a preliminary test for collecting data from companies, which has been made within the project, in terms of method and results.

After the conclusions and the formal information, there are three appendices:

1) An investigation and analysis of major train traffic interruptions in Sweden since 2000 and their effects on transportation customers
2) More technical information on the data collection test
3) A method developed within the project, for calculating operative costs for train transports due to delays, using the model TSDA. Operative train transportations costs is a part of VTTV and the model approach could be used as an alternative to collecting this data manually.

2 Frame of reference

In this chapter a brief Frame of Reference is given in order to help the reader understand our perception of the area of research which is a blend of transportation, logistics and CBA primarily.

Freight transport involves a multitude of shipments of different sizes, characteristics and requirements. It involves everything from a 5 000 tonnes slow moving iron ore train to a 100 gram express parcel. The purpose of the shipment could be to deliver a vital spare part that stops the production in an entire factory at huge costs or it could be a load of gravel that just is supposed to be dumped somewhere. This highlights the challenges in determining the effect of delays in the transport chain. The effects of a delay are very contextual. Sometimes a 1 hour late delivery of a single screw can cost millions while in other cases a 1 day late delivery of a shipload of screws can have negligible consequences.

Transportation and logistics systems that are the basis for goods transports are quite complex with different modes of transports and interdependencies between buyers, sellers, forwarders etc. The figure below gives a good survey of the different qualities of transportation and logistics systems and why they, on a larger scale, are so hard to model and understand. This is a network representation of the systems but of course there are processes taking place on these different networks and stakeholders who execute them. In the network we discuss nodes and links and different superposed or interconnected networks. A node here representing either a terminal, a cross-docking, a shop or any place were the goods is handled or stored. A link in analogy with this represents a road, railroad, waterway or airway. The networks represented either unimodal road-to-road transports or multimodal road-rail-road networks etc.

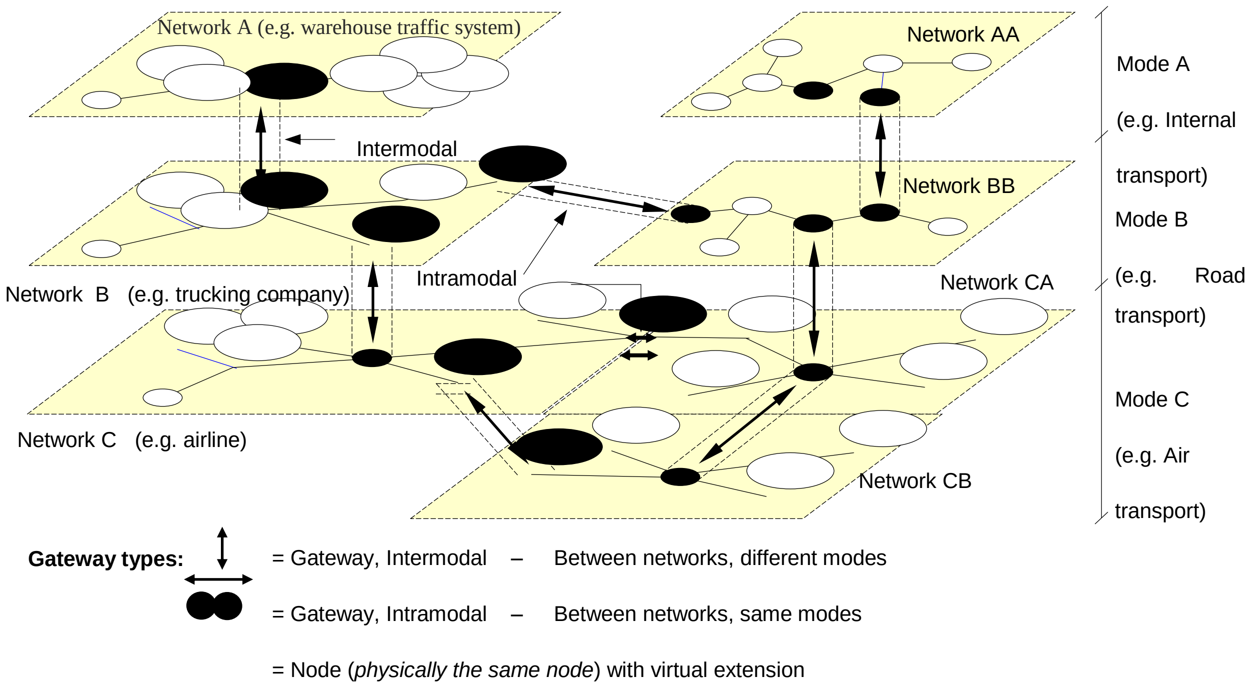

Figure 1: Different modes of transport, networks and gateways (Waidringer, 2001)

In the example, Network A represents the internal flow within a factory, warehouse or other entity. It is normally some kind of assembly if it is a factory and in a warehouse the two main activities are to break goods into smaller shipments and to consolidate small shipments into larger ones. Presently, quite a few other activities are performed in terminals and warehouses in order for third party logistics providers to strengthen their position and to add value to the base services. Network B is a road transport network that in theory is only limited to where there are roads; in practice the limitation is rather the extension of the network that the trucking company in question is operating. The gateway between the networks is marked with a dark circle and a double arrow indicating that the flow can go in both directions. Network C is an air transport network which, as is the road network, only limited to what destinations the airline company operates. Here the gateway, as for the other networks is a specific node where the two networks meet. For intramodal gateways, i.e. transfers between the same type of networks such as network B and BB in the figure, the gateway does not necessarily have to be a specific node. The right part of the figure shows equivalent networks to the ones on the left-hand side of the figure in order to indicate that there might be several parallel networks on all the different levels. The figure does not show rail and sea networks but the idea is the same and it should be sufficient to exemplify the idea of the vast interconnectedness of transportation and logistics systems.

A network represented like this basically exists of nodes and links describing an interconnected web which is a very good metaphor for both transport networks and terminals, which represents a common theory base. Wandel and Ruijgrok make the basic notion of networks and the correlation between the description of the transport industry as a network very clear in their paper (Wandel & Ruijgrok, 1995). The correlation between the infrastructure, the resources that move on the infrastructure and constitute the transportation network is shown in Figure 2 below.

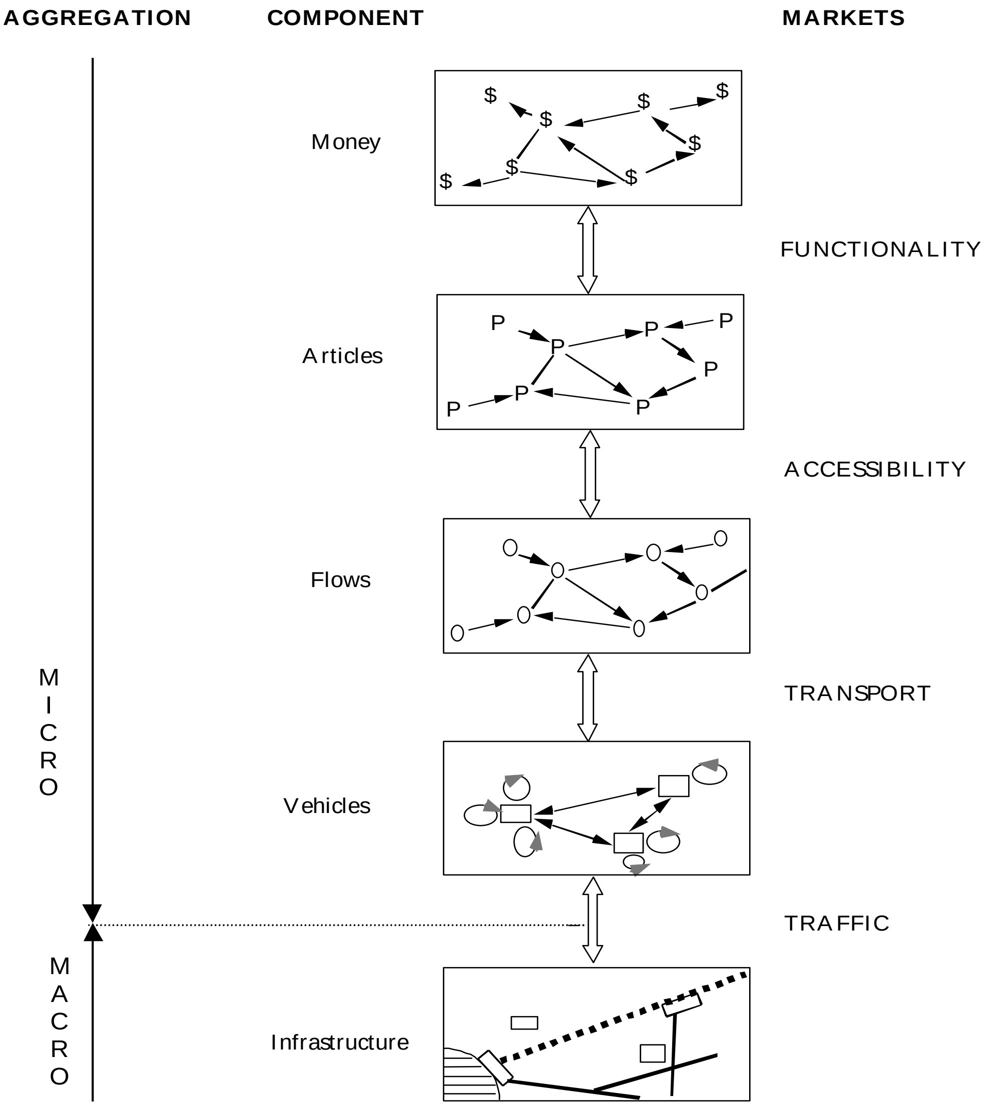

Figure 2: The transport network, resources and infrastructure (Wandel & Ruijgrok, 1995), (Here adapted from Waidringer 1999)

The figure describes the correlation between the aggregation level and the components of the system and the markets. The traffic is regarded as a market for infrastructure services, e.g. the trade of space and time. Transport is the market for the movement of vehicles on the infrastructure. The accessibility market are the market for flows (or slots) made available by the service providers operating on the transport market. Finally there is a market for functionality that is derived from the producer and consumer relations. The consumers buys (with money or equivalent) articles that gives the users a certain kind of functionality. The model could possibly be expanded to include the financial market including the macroeconomic scale but it was not regarded as useful to expand the model that far in this context.

2.1 Literature overview

This chapter gives an overview of literature primarily in the fields of CBA and VTTV estimations as wells as customer requirements and their valuation of these and the Samgods model system.

Estimation of VTTV

For VTTS – the value of freight transportation time savings – the position is relatively good, in terms of a rather large number of studies from different countries using different methods and reaching results of a similar magnitude. For example, Bickel et. al. (2005) illustrates this in the report for HEATCO. The fact that several different methods – stated preference, revealed preference and the cost savings approach – gives similar results increases the credibility for VTTS in infrastructure planning.

When considering VTTV, the value of freight transportation time variability, often termed VFTTV when there is a need to distinguish it from its counterpart for personal trips, basically all reviews on the subject has reached conclusion that transport time variability is an important factor to include in a freight transport related cost-benefit assessment. For example de Jong et al., (2004), expresses "All the studies on the value of reliability that were reviewed agree that reliability is a factor of **substantial importance**: there were no studies that concluded that this factor can be neglected." Zhang et al. (2004, p.95), concluded that there were evidence from a number of studies indicating that reliability is more important than transport time savings for freight transports, and Bickel et al., (2005, p. 143), claimed that "there can be no doubt, given the qualitative and increasing quantitative evidence, that the benefits from increased reliability of commercial goods traffic will make a substantial contribution to the total time-related benefits to commercial goods traffic."

However, unlike the situation for VTTS for freight, there is no consensus on dimensions and units for transport time variability and on the eventual range of values for VTTV. This was the conclusion of the expert workshop on the subject that was reported in de Jong et al., (2009). All cited studies concluded that further research were necessary in the area.

The reason for the divergent results on VTTV is sometimes, e.g. in Bickel et al. (2005), given as partly a deficiency in the number of conducted studies. However, transport time variability seems to have been part of a majority of studies on VTTS for freight the last three decades. For example, Bruzelius (2001) has transport time variability included in 21 studies out of the 35 reported studies. From this, it does not seem plausible that it is the number of studies that is the cause of divergence in results for VTTV. One important factor for this may be the multitude of different measures of transport time variability which have been used in the studies. The most common measure used in the studies is to present the variability as the share of transports (of similar kind) which are delayed more than a specified time. Another commonly used measure is expected delay; however, an expected delay does not really capture variability. The rather huge number of different measures of variability makes comparison of results difficult. One measure of variability, which could be termed, a natural measure for cost-benefit assessments, is the standard deviation of transport time. This has not been used in any study during the last three decades. It has been deemed as putting a too high cognitive burden on the respondents (de Jong et al., 2004).

The SP-method is almost exclusively the only used method for studies on VTTV. This is a contrast compared to VTTS, where SP, RP and the cost savings approach has been used. Since all these method gives comparable results for VTTS, they are supporting each other in order to reach a consensus on the plausible magnitude on VTTS for freight.

Table 1 Studies of VTTV for freight as presented in Bruzelius (2001)

Study	Year of data	Mode/ Country	Value	Unit Value per	Comment
Transek (1990)	89/90	Rail/S	SEK 60 same day	1 % unit & shipm	Non-linear
Transel (1990)	89/90	Rail/S	SEK 40 next day	1 % unit & shipm	Non-linear
Transek (1990)	89/90	Road/S	SEK 150 same d.	1% unit & shipm	Non-linear
Transek (1990)	89/90	Road/S	SEK 30 next day	1% unit & shipm	Non-linear
Transek (1992)	1991	Road/S	SEK 280 same d.	1% unit & shipm	Non-linear
Transek (1992)	1991	Road /S	SEK 110 next day	1% unit & shipm	Non-linear
Kurri et al. (2000)	1997	Road/SF	$ 47.47	hour & ton	Expected delay
Kurri et al. (2000)	1998	Rail/SF	$ 0.50	hour & ton	Expected delay
Wigan et al. (2000)	1998?	Road/AUS	AUS$1.25-2.56	1% unit & pallet	
de Jong et al. (2001)	2000	Road/F	Not reported	1% unit & shipm	SP+RP
"	2000	Rail/F	"	"	"
"	2000	Com-bined/F	"	"	"
Winston (1981)	75-77	Road/US	$ 404	day, standard dev.	RP
Winston (1981)	75-77	Rail/US	$299-4110	day, standard dev.	RP
de Jong et al. (1992)	91/92	Road/NL/	Not reported	1% unit & shipm	Non-linear
"	"	Rail/NL	Not reported	1% unit & shipm	"
"	"	IWT/NL	Not reported	1% unit & shipm	"
Fowkes et al. (2001)	00/01	Road/UK	£ 61.5-167.6	hour & spread	Partly opera-tors
de Jong et al. (2000)	94/95	Road/UK	Not reported	1% unit & shipm	Partly opera-tors
de Jong et al. (1995)	1995	Road/D	Not reported	1% unit & shipm	Non-linear
"	1995	Road/NL	Not reported	1% unit & shipm	Non-linear
"	1995	Road/F	Not reported	1% unit & shipm	Non-linear
Bergkvist et al. (2000)	1991	Road/S	SEK 165 same d.	1% unit & shipm	
"	1991	Road/S	SEK 84 next day	1% unit & shipm	
Bergkvist (2001)	1991	Road/S	Not reported	1% unit & shipm	
INREGIA (2001)	1999	Road/S	SEK 63	1 per mille & shipment	From linear model
"	1999	Rail/S	SEK 1142	1 per mille & shipment	From linear model
"	1999	Air/SWE	SEK 264	1 per mille & shipment	From linear model
Small et al. (1999)	1995?	Road/US	$ 371.33	hour & shipment	Expected delay, op-erators

Customer requirements

The general customer requirements on freight transport are well known and several studies have come to the same conclusion, e.g. (Flodén, *et al.*, 2010), see Table 2 below.

Table 2 Literature review of factors influencing transport buyer's choice of transport service (Flodén et al 2010)

Authors	Year	Methodology	Analysis technique	Country/region studied	Author type	Type	Peer reviewed
Widlert	1990	Interviews face-to-face (SP)	SP	Sweden (Northern region)	Consultant	report	No
Fowkes, Nash & Tweddle	1991	Interviews (SP)	SP, RP	UK	University	article	Yes
Anderson & Browne,	1992	Face-to face Interviews (SP)	SP	UK	University	conference	Yes
Widlert & Lindstedt	1992	Interviews face-to-face (SP & RP)	SP & RP	Sweden	Consultant	report	No
Fridstrøm & Madslien	1995	Interviews	qualitative analysis	Norway	Research institute	report	No
Hellgren	1996	Questionnaire	statistical analysis	Sweden	University	licentiate	Yes
Golias & Yannis	1998	Interviews (SP & RP) (structured)	SP, RP	Greece	University	article	Yes
Rohani & Lumsden	1998	Questionnaire	Statistical analysis	Europe	University	conference	Yes
Ludvigsen	1999	Interviews, telephone (RP)	statistical analysis (factor & regression)	Sweden	University	article	Yes
Laitila & Westin	2000	Questionnaire, mail (SP)	SP	Sweden	University	report	No
Björklund	2002	Interviews	qualitative analysis	Sweden	University	licentiate	Yes
Maier, Bergman & Lehner	2002	Interviews	qualitative analysis	Austria (four regions Villach/Klagenfurt, Linz/Wels, Graz and Vienna)	University	article	Yes
SIKA	2002	Questionnaire	statistical analysis	Sweden	Research institute	report	No
Bolis & Maggi	2003	Interviews (SP)	SP	Italy & Switzerland	University	article	Yes
Vannieuwenhuyse, Gelders & Pintelon	2003	Questionnaire (Internet)	statistical analysis	Belgium (Flanders)	University	article	Yes

Berdica et al.	2005	Questionnaire (telephone)	descriptive statistical analysis	Sweden (Jönköpings, Värmlands and Örebro)	Consul tant	report	No
Björklund	2005	Questionnaire (mail)	statistical analysis	Sweden	Univer sity	dissert ation	Yes
Danielis, Marcucci, & Rotaris	2005	Interviews, Face-to-face (SP)	SP	Italy (2 regions)	Univer sity	article	Yes
Lundberg	2006	Interviews, telephone (SP)	SP	Sweden	Univer sity	licentia te	Yes
Punakivi & Hinkka	2006	Interviews (semi-structured focus) & Internet survey	qualitative & statistical analysis	Finland	Univer sity	article	Yes
Danielis & Marcucci	2007	Interviews, telephone & face-to face	SP	Italy	Univer sity	article	Yes
Dinwoddi e & Vandewal	2007	Questionnaire	statistical analysis (hypothesis testing)	Netherlands (region in south)	Univer sity	confer ence	Yes
Engström	2007	Questionnaire & interviews	qualitative & statistical analysis	Sweden	Univer sity	confer ence	Yes
Lammgår d	2007	Interviews, questionnaire (mail)	qualitative analysis, statistical analysis (factor and correlation)	Sweden	Univer sity	dissert ation	Yes
REORIEN T	2007	Questionnaire	statistical analysis (factor analysis)	Nordic countries and countries in Central- and South Eastern Europe	EU project	report	No
Chiara et al.	2008	Interviews (telephone)	SP	Italy	Univer sity	article	yes
Posten	2008	Questionnaire (telephone)	statistical analysis	Sweden, Denmark, Finland, Norway	Comm ercial	report	No

The transport customers state that they focus on transport quality, reliability and transport time. Naturally, the cost is also of high importance. The customer requirements can be seen as an indication of areas where the customers perceive that a breach, e.g. by late deliveries, could have a high impact.

Transport quality

Transport quality is a rather vague concept that is not properly defined in the studies but ranked highly by the customers. Its importance is not surprising as it is difficult to imagine any situation where a transport customer would request a low transport quality. Transport quality could include more or less anything related to how well the transport is performed. Common attributes mentioned in the studies are risk of goods damages, on-time delivery, flexibility to change, risk of theft, how transport companies fulfils their promises, friendly customer contact, etc.

Reliability

One of the most important factors is to have reliable transport. This means that the transport should be delivered on-time as promised. This on-time delivery is considered more important than the transport time. Thus, the customers prefer a slower transport where they know the exact delivery time instead of a faster transport with low reliability. The acceptance for low reliability increases with longer transport distances.

Transport time

A short transport time is considered important in some studies, but the importance diminishes with a longer transport distance. Thus, the longer the transport distance, the less importance is placed on having a fast transport. The importance of transport time is also dependent on contextual factors, such as the type of supply chain and type of industry. In general, customers are willing to pay extra for faster deliveries, but not to pay less for slower deliveries.

Cost

When it comes to selecting a transport solution, cost is ultimately ranked as the most important factor. However, it is not only about getting the lowest cost but the basic quality requirements must also be fulfilled. The selection of a transport solution is thus a two-step procedure. First, options that do not fulfil the quality requirements are removed. After that, the customer almost only focuses on the cost of the remaining alternatives.

Other factors

There are many other factors which normally have less importance for the mode choice as:

- Frequency
- Flexibility
- Availability
- Possibility to reach all customers
- Adoption to the logistic system

A commonly discussed factor is the environment and CO_2 emissions. However, when looking at the customer requirements, environmental issues are given a low priority. Most customers vaguely expect the transport companies to be “environmentally friendly”, but they have no specific requirements or checklists and, most importantly, they are sometimes willing to pay only a few per cent extra (Lundberg (2006) says 3-5%) for a transport that gives less environmental impact.

Other factors with a low importance are mode of transport where few customers have specific requirements. Goods damages and IT support are also ranked low and not perceived as problematic.

Freight customers' valuation of delays

Lundberg (2006), also referred to above, contained both a questionnaire with multiple-choice questions or open answer options and an SP study. What distinguishes this study is its very high response frequency. Out of a selection of 100 transport managers, 99 took part in this telephone interview, which was supported by an interview form that had been sent to them beforehand. Respondents were selected from different industries throughout Sweden and represented companies that used rail, road and shipping. In this summary, the responses are presented for some questions related to delays. Since there were 99 companies, 10 companies represent approximately 10% of the total.

Occurrence of delays

One question concerned the proportion of transportation in the biggest outflow that arrived late at the recipient as a percentage of annual transportation. Only limited information on delays was available but the respondents estimated the occurrence of delays as shown in Table 3. 18 companies, or 18%, considered that they had only a few or almost no delays at all. 46% had between 0.5 and 4% delayed shipments. 19% had delays of between 5% and 10% and 6% had delays of between 20% and 30% of their total transportation.

Table 3: Summary of the responses to the question: "What percentage of your total transportation is delayed?"

Delayed shipments	Number of companies	Share %
0%	18	18%
0.5-1%	40	40%
2-4%	16	16%
5-10%	19	19%
20-30%	6	6%
Total	99	100%

Additional costs due to delays

A delayed consignment may mean extra costs for the consignor or the recipient. One question concerned how long a delay must be for it to cause the company or recipient additional costs. The results are shown in Table 4 and Figure 3.

9% did consider that they had an additional cost from the first minute a consignment was delayed. 45% had an additional cost if the consignment was 2-8 hours delayed. After 1 and 2 days respectively, 21% and 10% of the companies said they had an additional cost. 11% considered that they had an additional cost after 3 days' delay.

It is clear that the impact of the longer delays is clustered to even days with 24, 48, 72 and 96 hours' delay. This was an open question so the transport managers were able to choose the number of hours but the diurnal rhythm is evidently important with regard to freight transportation.

Table 4: Summary of the responses to the question "When does an additional cost arise as a result of delays?"

Delay hours	Number of companies	Share %	Category %	Category delay
1	9	9%	9%	1 hr
2-3	17	17%		
4-6	17	17%	45%	2-8 hrs
6-8	11	11%		
16	1	1%		
24	21	21%	21%	1 day
36	2	2%		
48	10	10%	10%	2 days
72	2	2%		
>96	9	9%	9%	4 days
Total	99	100%		

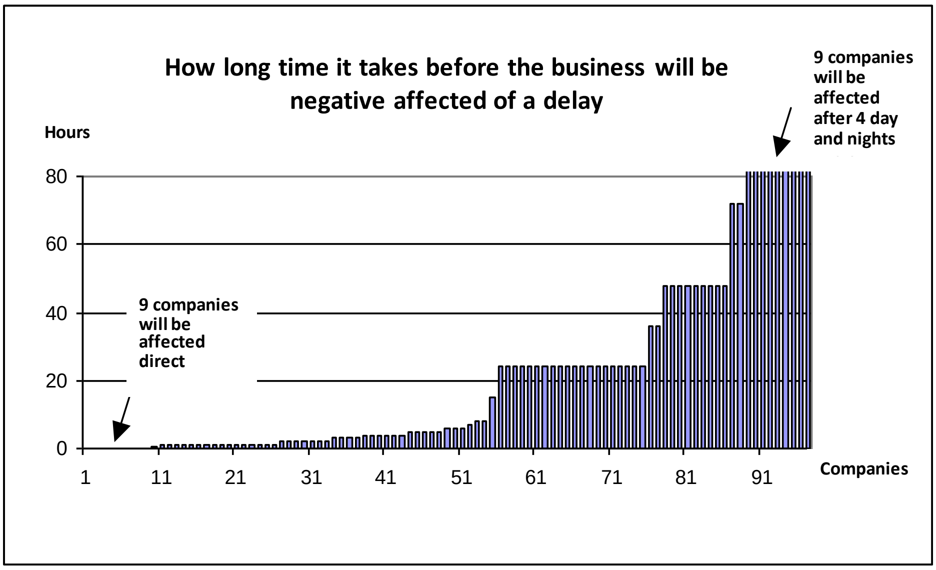

Figure 3: Responses to the question “When does an additional cost arise as a result of delays?” Source: Lundberg (2006).

Transportation time

It is of interest to relate the results to transportation time. Transportation time varies as shown in Table 5. 28% of the companies had a transportation time of less than 5 hours, which can be interpreted as meaning that transportation takes place over the day. 33% had a transportation time between 6 and 25 hours, which can be interpreted as meaning that transportation takes place at night or takes one day and one night. 11% had transportation that took 2 days, during which the whole of Sweden can be reached by road and rail, as can the Nordic region and parts of Europe. 16% of the companies had transportation that took between 3 and 4 days; most of Europe can in principle be reached in that time. 11% had transportation that took longer than 4 days; the whole world can be reached in this time.

Table 5: Transportation time for the companies studied.

Transportation time (h)	Number of companies	Share %	Category %
<=5	28	28%	Over day
6-10	22	22%	Over night
11-25	11	11%	Over night+day
26-49	11	11%	1-2 days
50-99	16	16%	3-4 days
>100	11	11%	>4 days
Total	99	100%	

3 Transport attributes influenced by delays

It is first important to understand the logistical and transport processes involved to understand the effects of delays. The activities in a typical transport chain are therefore described. Key activities that potentially are affected by a delay are <u>underlined</u>.

Transport in its simplest form is performed by a vehicle in a mode of transport that picks up goods at an origin and delivers it at a destination. The <u>transport</u> itself can be performed in several steps where the goods are <u>transhipped</u> between different vehicles and different modes of transport. The transport can also pass one or several terminals where the transhipment takes place and where goods from different origins and to different destinations are sorted and consolidated onto new vehicles. When the shipment is <u>delivered</u>, the transport vehicle and driver will continue <u>with other planned assignments</u>. The shipment will be unloaded when the vehicle arrives at the destination.[4] The goods will then be moved to a warehouse or directly <u>for use</u> e.g. in production or for sale in a store.

3.1 Factors influenced by delays

Based on the activities identified in the typical transport chain, a number of key factors influenced by a delay can be identified. For each activity, the key factors are highlighted in **bold** and described. The cost drivers behind the costs are highlighted in *italics*.

Transport

The transport involves a vehicle and staff, e.g. driver. Any delay means that the transport will take longer, thus requiring a larger share of the **vehicles capital costs** and **vehicle related staff salary costs**. This can also be referred to as the **time dependent vehicle costs**. *Longer transport time* will also mean that a larger share of the **goods capital costs** can be allocated to the transport. However, this does not necessarily mean that the total capital cost for the goods will increase. If the goods was only intended to be placed in a warehouse and not directly used, then the total goods capital cost for the supply chain will be the same. If the delays are caused by events that require a detour, e.g. a blocked road, then the **distance dependent transport costs** will also increase due to a *longer transport distance*, e.g. fuel consumption and driver costs.

[4] (some rail transports are shifted between feeder trains and wagonload trains, in which case the wagons may be rearranged at blocking yards without loading/unloading).

A *transport system with a high uncertainty* will also require the transport company to plan for backups, thus incurring an **indirect cost for backup and flexibility**. This can include purchasing more trucks than actually needed to have spare capacity or scheduling an extra train set instead of running a “tight” time table. These are costs that are hard to allocate to a specific shipment as they are incurred at a system level before the delay has occurred. The driver and vehicle is often also scheduled to continue with *other planned assignments* after the delivery has been made. Any delays therefore risks spreading through the network and incurring **delay costs for other shipments**. This effect is often avoided or reduced by *redirecting other resources to the planned assignments*, thus incurring a **direct cost for backup and flexibility**.

Transhipment

A transport is sometimes a combination of several shorter transports where the goods are moved between different vehicles and modes of transport. This occurs at terminals which have staff and given opening hours. A delay might result in that the vehicle will arrive after the *scheduled opening hours* and thus incur further **time dependent vehicle costs** for waiting until the terminal opens or **overtime costs for the terminal staff** to extend the opening hours. A late delivery might also *disrupt the operational planning* at the terminal, resulting in that there is no staff available to handle the shipment on arrival and forcing the vehicle to wait with further time dependent vehicle costs.

The transhipment can also include consolidation with other shipments. This means that part of the goods on the incoming vehicle will be combined with goods from other vehicles onto a common vehicle with the same destination. This is the typical operations of terminals in a less-than-truckload (LTL) network. A late arrival can cause the shipments to *miss the planned transhipment* and delay them until the next possible transhipment option. This will incur increased **goods capital costs** and **terminal storage costs**. In many LTL-networks, the departures are only daily, which would mean a one day delay. In other networks, e.g. trans-ocean shipping, the next departure could be days or weeks away. This brings a sharp rise in the delay costs once the departure is missed, or in other words: If you miss the train, it is not important if you miss it by five minutes of five hours. The cost will be the same.

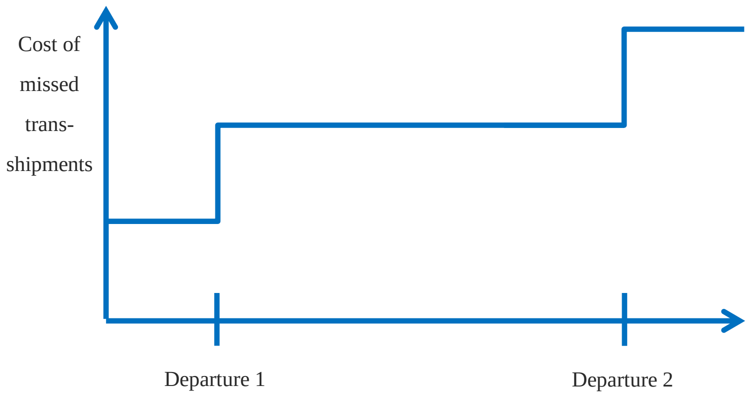

Figure 4: The costs of missed transhipments

The effects of a missed transhipment will also depend on the size of the network as a large network, e.g. one of the large forwarders, commonly have more departures and flexibility and thus more easily can adapt to disruptions than a small network.

Delivery

Similar to the issues concerning transhipment, a late delivery might incur **overtime cost for the receiving staff** or **time dependent vehicle costs** if forced to wait. The receiving company will have given *opening hours* and commonly, the arriving vehicles are given "slot times" when they are allowed to unload their goods. Missing the slot time *disrupts the operational planning* and forces the vehicle to wait to be unloaded.

Use of goods

The goods delivered naturally have an *intended use* with the receiver. This could be many things. Some goods will go directly into production, e.g. in a JIT-system, or directly for sale in a store. Other will be placed in a warehouse for further use. The effects of a delay will depend on the intended use of the goods. If it is intended for direct use, the costs will be high. **Direct cost of lack of goods** could include cost for idle equipment and staff and overtime costs to catch up with production. **Indirect costs of lack of goods** could include cost for lost sales, e.g. when a product is not available in a store, or lost customers, e.g. when a customer changes to another supplier due to unreliable supply. Naturally, these costs are very situation dependent and hard to generalise. They depend on the *type of industry*, *type of goods* and *size of shipment*. For example, the automotive industry with a large use of JIT-logistics will be more sensitive to delays and incur higher delay costs than the general manufacturing industry. The type of goods impacts the delay costs both due to its value and goods characteristics. Capital cost of the goods depends on the goods value. Goods characteristics, such as perishability or fashion, can cause the goods to suffer reduced value during the delay. Often, the goods characteristics can be derived from the type of industry. The size of shipment affects the delay cost as the delay of a large shipment is harder to compensate for than the delay of a small shipment. A large volume is less likely to be available in stock or possible to source from alternative locations.

The industry tries to counteract these effects by using safety stock. A safety stock is an extra stock of goods that is kept as a backup to avoid goods shortages. *Unreliable transport* will force the industry use a larger safety stock than otherwise necessary, which will incur an extra **cost for safety stock**.

Propagating effects

The previous description has shown the costs and cost drivers for each part of the transport chain. However, it is important to remember that the effects of a delay will also propagate down the transport chain. Longer transport time, might for example result in that the transhipment is missed and that the shipment is delivered late to the receiver. The risk that the **delay will propagate in the transport chain and cause other delay costs** depends on the *time margin between the different steps* of the transport chain. Also it will be influenced by where in the chain the delay occurs, earlier occurrences potentially cause dependent delays later in the chain. A *transport system with high uncertainty* will require the transport companies to plan for this and add more margins, thus increasing total transport time and thereby increasing the **goods capital costs**.

3.2 Categorising the effects

The key factors and cost drivers identified can be used to calculate the costs of a delay. A challenging factor is that in many cases the effects are very situation dependent, i.e. depending on the design and operation of the current transport chain. For example, if two trucks are caught in the same queues, one might have planned for small time margins and will suffer an added delay cost while the other truck might have planned for possible delays and instead suffer an indirect cost for backups and flexibility for all transports, but no additional cost for the current delay. Similarly, if a truck is 15 minutes late for a transhipment, one terminal might be willing to extend their opening hours to receive the truck, while another terminal might refuse.

The variables can be grouped into categories based on their main background variables. Building on the previous discussion on the factors influenced by delays it can be seen that most variables are either related to logistics issues or to business related issues with the receiving company. The variables are therefore appropriately grouped into the two categories Business effects and Logistics effects. A third group is the System effects that are caused by the design of the system based on the perceived reliability of the system. The variables are summarised in Table 6.

Business effects

Business effects occur from the effects on the receiver of the goods business operations when the goods are delayed, e.g. idle equipment, extra handling costs etc. These effects can be traced back to the **type of goods**, as different types of gods will have different use, e.g. raw material or finished products. This makes it appropriate to divide the costs according to the type of goods. The type of goods is also related to the type of industry as similar industries can be expected to use similar goods. However, this dependence is considered weaker as most industries can be expected to receive goods of many types although further studies might be needed to validate this link. Note that as some dependence exists it might also be possible to use industry type to approximate the type of goods if goods statistics is lacking. The use of type of goods as the main categorisation is also well in line with current modelling approaches and statistics for transport planning were type of goods is one of the main variables used.

The business effects also include effects from the value of the goods, e.g. capital costs. These effects are easiest summarised at the end of a transport chain where the total length of the delay is known. It is possible that a delay in one part of the chain might be balanced by planned margins etc. and thus not resulting in any delay for the end receiver and therefore also not any extra capital costs. Thus, the capital costs of delayed goods during transport are summarised at the end of the transport chain. The capital costs are dependent on the type of goods.

Logistics effects

Logistics and transport effects results from the transport activities and can be divided into two categories: link effects and node effects.

Link effects

Link effects are the effects that occur in the transport links due to the delays, e.g. extra salary costs or capital costs. The transport effects are dependent on the **type of transport vehicle** used, e.g. type of lorry, type of train etc. The transport related delay costs are strongly related to the physical transport costs and thus to the type of vehicles used and less dependent on the goods on the vehicle. It is therefore appropriate to allocate the effects according to the vehicle type.

It is also not considered feasible to find appropriate input data on how transport costs are related to goods type. The cost of operating a type of vehicle is in all essential the same independent of what is loaded in the vehicle, although it could be argued that the type of goods will affect the transport design, e.g. that more backup resources are assigned to perishable goods or that JIT-gods are given higher priority. It should be noted that it is possible to in the future extend the method by assigning different values to the link effect according to both vehicle type and goods type if appropriate data becomes available.

Node effect

Node effect is the delay effect that occurs in the nodes, e.g. terminals. For example, cost of missed transhipment or extended opening hours. These costs can be considered dependent on the **type of transport vehicle**, as the type and size of vehicle will determine the handling and storage resources needed. It is not advisable to allocate the costs according to type of terminal, as e.g. the same terminal can service several different types of vehicles with different costs. For example, the effects of a delayed train to an intermodal terminal are different than the effects of a delayed lorry to the same terminal. Note that there might be different vehicles used transporting into a terminal and transporting out from a terminal. However, the inbound vehicle should be used as the delay costs are related to the late inbound transport.

Node effects should also be attributed to the last node in the chain, i.e. the receiving company, as their operations for receiving the goods and related delays costs, e.g. extra staff costs, are similar to the costs incurred in the terminals.

System effects

System effects are the effects caused by the overall system design, e.g. planned margins or backup resources. This factor is linked to the perceived reliability of the transport system which can be considered dependent on the **transport mode** used. Transport mode in this perspective represents the combination of modes used for the total chain, e.g. unimodal road or intermodal transport. Although the type of mode is highly related to the vehicle used, it cannot be allocated directly to the type of vehicle since several vehicle types can be used in a chain and the overall perceived reliability is determined by all modes used combined.

Adding the effects for a chain

The current structures allows for the effects of a transport chain to be calculated by simply adding up the different steps. Thus, the effects a of chain with goods type X with vehicle type A $\rightarrow$ terminal $\rightarrow$ vehicle type B $\rightarrow$ receiver is calculated by adding (link effect vehicle A) + (node effect vehicle A) + (link effect vehicle B) + (business effect goods X) + (node effect vehicle B) + (system effect mode AB).

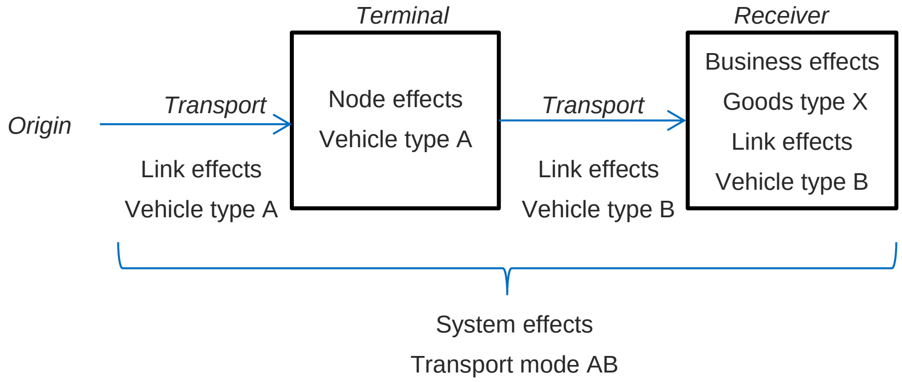

Figure 5: Summing up the effects for a chain

Business effects are considered separate from transport effects to avoid the problem of double counting the effects in a transport chain. If the business effects were included in the transport costs, the costs would be counted once for each link in the transport chain although they only occur once for the receiver. The current division allows for the different factors to be handled separately and added.

3.3 Summary of effects

The activities, costs, cost drivers and variables are summarised in Table 6.

Table 6: Activities, link effects, costs and cost drivers for delays

Activity	Category	Division by	Cost	Cost driver	Key variables
Transport	Link effects	Type of vehicle	Time dependant vehicle costs	Longer transport time	Vehicle costs, length of delay
			Distance dependent transport cost	Longer transport distance	Vehicle costs, extra transport distance
			Direct costs for backup and flexibility	Redirecting other resources to take over planned transport assignments	Cost of extra transport
			Delay costs for other shipments	Current delay causes other planned transport assignments to be delayed	Transport chain effects, other cost drivers
	Business effects	Type of goods	Goods capital costs	Longer transport time	Goods value, size of shipment, length of delay
	System effects	Transport mode	Indirect costs for backup and flexibility	Unreliable transport system in general	Perceived reliability, cost of backup
Transhipment	Node effects	Type of vehicle	Time dependent vehicle costs	Arriving outside opening hours or disrupting terminal operational planning	Vehicle costs, length of delay
			Overtime costs for terminal staff	Arriving outside opening hours or disrupting terminal operational planning	Staff costs, length of overtime
			Terminal storage cost	Missed transhipment	Terminal storage costs, size of shipment, length of delay
	Business effects	Type of goods	Goods capital costs	Missed transhipment	Goods value, size of shipment, length of delay
Delivery	Node effects	Type of vehicle	Overtime cost for receiving staff	Arriving outside opening hours or disrupting terminal operational planning	Staff costs, length of overtime
			Time dependent vehicle costs	Arriving outside opening hours or disrupting terminal operational planning	Vehicle costs, length of delay
Use of goods	Business effects	Type of goods	Direct cost of lack of goods	Use of goods	Type of industry, type goods and size of shipment, effects of lacking goods
			Indirect cost of lack of goods	Use of goods	Type of industry, type goods and size of shipment, effects of lacking goods
			Cost for safety stock	Unreliable transport system in general	Perceived reliability, cost of safety stock
Chain perspective	System effects	Transport mode	Propagating delays in the chain causing other delay costs	Too small time margins between steps in the transport chain	Characteristics and complexity of transport chain, other cost drivers
			Goods capital costs	Unreliable transport system in general	Goods value, perceived reliability

This chapter only covers the effects of delays, but it is important to note that also too early deliveries might cause large costs. The logistics system has planned to receive the goods at a given time and if it arrives earlier than that, several of the extra costs normally associated with delays might occur. For example, extra personnel might be needed or a surplus of perishable goods might have to be sold at a discount etc.

3.4 Magnitude and frequency of disruptions

The effects of delays caused by the identified factors and drivers are also influenced by the magnitude and frequency of the disruption causing them. A disruption is some unforeseen occurrence in the transport system that causes a delay, for example a traffic accident, extreme weather, congestion, planning mistake etc. The magnitude of the disruption is the size of it, which can be approximated by the length of the delay it causes.

Most disruptions in the freight transport system are of small magnitude, e.g. traffic congestion causing a 20 minute delay. These are frequently occurring but are also expected by the designers of the transport system. Therefore, most transport systems are designed to absorb these small disruptions only with minor consequences, e.g. by planned margins in the time tables or by safety stock. However, the consequences of the disruption increases once the magnitude of the disruption increases past the planned margins. Further studies are required to investigate how the effects of the delay increases with the time of the delay, but most likely it will be an exponentially increasing curve, i.e. the effects of the delay on the 10th day are much higher than on the second day. It can be assumed that the longer the delay lasts, the harder it will be for a company to manage the consequences.

However, the large magnitude disruptions are less commonly occurring than the small ones which are why they are not planned for in the design of the transport system. The system designers make plans of disruptions that happen once per week but not for disruptions that happens once every decade.

It is important to point out that this picture is a conceptual model. What constitutes the border between "small" and "large" or "common" and "rare" will vary between different, industries, commodities, transport modes etc. However, a special investigation (Appendix 1) shows that big disruptions have been more common in the last decade depending on extreme weather caused by the climate change and heavy traffic in combination with lack of maintenance. For example, a 3 hour delay of a pallet in a JIT-system will be considered large, while the same delay of a ship in trans-ocean shipping will be considered small. The study in Appendix 1 shows that in Sweden, an average of 2.5 interruptions per year lasted 5 days and affected approximately 50 freight trains.

The effects of the magnitude and frequency of disturbance are summarised in the figure below, describing the four main types of disruptions and consequences.

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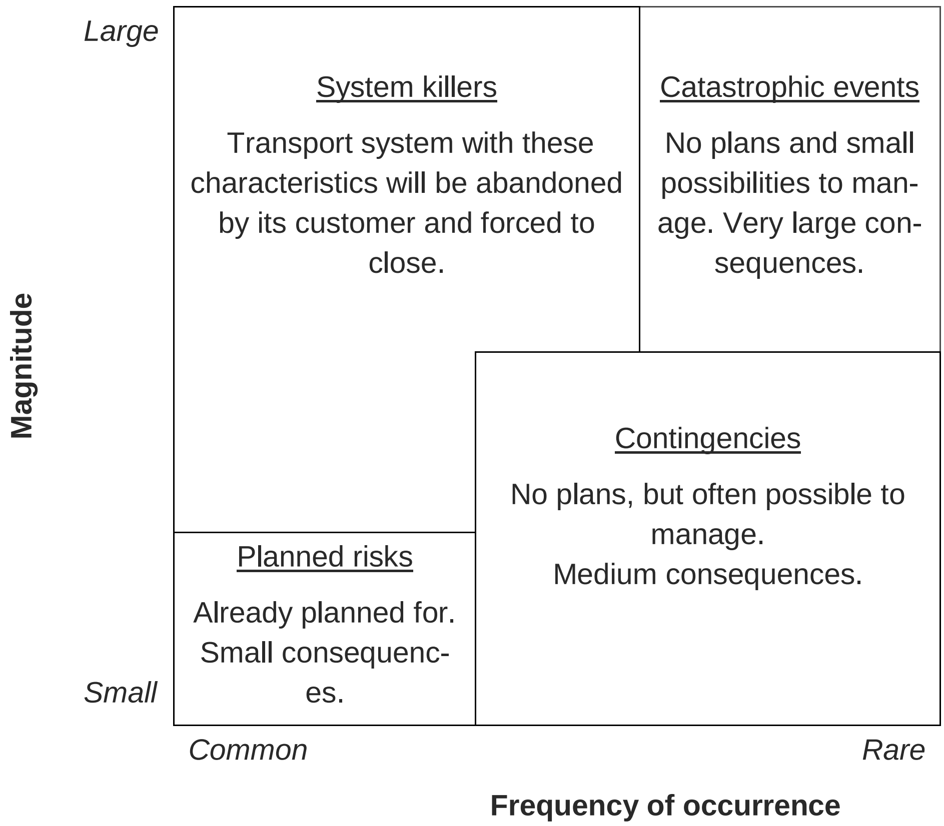

Figure 6: The four types of disturbances

Risks

The effects can also be explained using the concepts of risk, threat and vulnerability. A threat is a disruption that can potentially cause harm to the transport system, for example, congestion or accidents. Vulnerability is some flaw in the system that allows the threat to harm the system, e.g. lack of backup plans or no other possible route to take. When threats and vulnerability overlap, it becomes a risk. The size of the risk is the probability that the vulnerability takes place combined with the consequences of it. For example, a congested road is only harmful for the system (threat) if road transport is used (vulnerability) so that the transport is delayed (risk). The risk is high if the likelihood that the transport will be delayed by congestion is high and the potential damage from it is high.

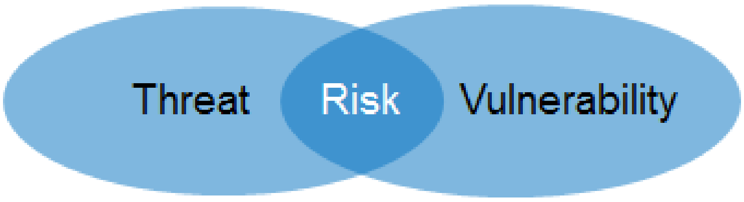

Figure 7: The relationship between threat, risk and vulnerability

The four types of disruptions and consequences can be described based on their risks. As can be seen below, the main risks occur among the rarely occurring disruptions with small magnitudes. The other risks are either already planned for or very rarely occurring.

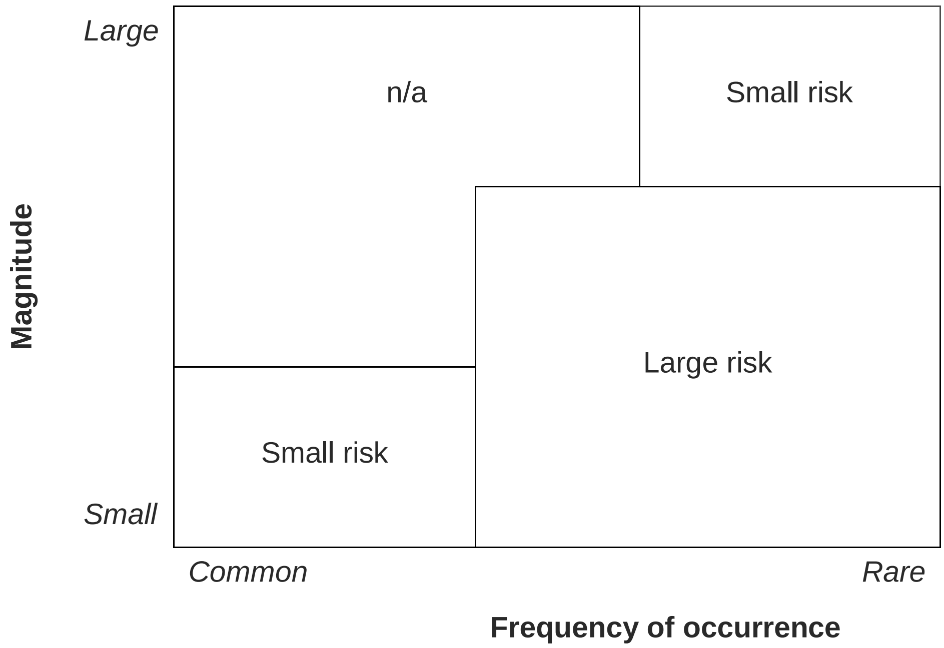

Figure 8: Size of risks

Calculating costs for different risks

Based on this division into four type of risk situations it becomes possible to outline different strategies for calculating the costs of the risks.

System killers (Large – Common)

This type of risks can be ignored since they are unlikely to occur over any longer timeframe.

Catastrophic events (Large – Rare)

This type of risks does occur, but are very hard to realistically include in an average cost estimate since they are so rare. They are better handled as extraordinary events in separate analysis than in an average estimate. The special investigation in Appendix 1 (as referenced earlier) shows that in Sweden an average of 2.5 interruptions a year thus lasted 5 days and affected approximately 50 freight trains. 2/3 of the operations were handled with diversions. So this problem is not negligible any longer.

Planned risks (Small – Common)

These risks are most appropriately approximated by safety stock and cost for back-up and flexibility. These events are within the span that the actors consider normal and already plan so that the disruptions are minimal. Thus, it can be assumed that these events do not result in any significant consequences.

Contingencies (Small – Rare)

These risks are harder to calculate as they do have a real impact on the transport system, but there are no ready made plans for them. This makes them situation dependent and hard to generalise. However, this is where the main risk occurs which makes it necessary to still include them and to some extent generalise them.

3.5 Selection of factors to include

Not all factors are possible to include in a model. The fundamental idea behind this project has been to build a model of a scope that can be supported by available data and that is in line with existing modelling tools for national transport planning.

The selection of factors to be included in the proposed model can be explained by the scope of variables, range of costs, and scale of effects. The scope represents the areas included, the range the variables included and the scale the size of the delay.

Scope of variables

The scope represents the areas included by the factors, for example what types of disturbances that should be included. This can be explained by looking at Figure 6 with the four types of risks and disturbances. Note that, as previously stated, the figure is conceptual and the size of the different fields may vary.

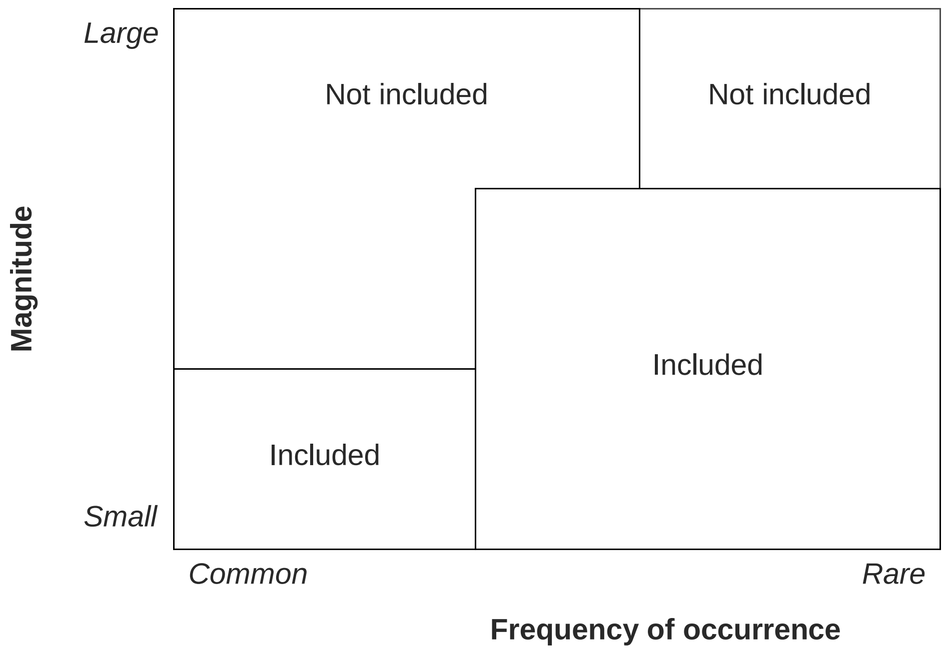

Figure 9: Scope of variables

The rare and large magnitude disturbances are not included. They simply occur too infrequently. Also, they are very hard to estimate correctly. As previously stated, they are recommended to be handled in a separate analysis. This is also in line with current principles for passenger transport in the Swedish national planning where “rare events with very large consequences” are recommended to be described qualitatively (Trafikverket, 2012, p. 22). Some industries are more or less dependent of a specific mode i.e. rail is a part of their logistic system between different production units. In these cases is it important to include also longer interruptions in the transport system in the investigations and calculations.

Range of costs

The range of costs included can be based on the variables in Table 6. It is suggested that the division into Business effects and Logistics effects is used for the model. System effects are included to the extent that Business and Logistics effects due to delays propagating in the chain are included, but other types of system effects are excluded. These types of effects are largely dependent on the perceived reliability of the transport system and design preferences, which is not considered feasible to estimate and quantify. These effects are very situation dependent and can vary from transport planner to transport planner. The perceived reliability is also a subjective judgement that could rapidly change and should therefore be avoided.

Further studies are required among the Business effect variables and Logistics effect variables to determine which costs that are to be included in estimating the delay effects. A preliminary recommendation is to not include the indirect costs, e.g. lost customers due to delays and planned extra margins, since they are very hard to estimate and situation dependent. This seems as a fairly uncontroversial recommendation since the system used for CBA-assessments, Samgods/Samkalk, anyway assume a fixed inelastic demand for the consumer goods. Also, it is recommended to exclude costs for other planned shipments that are delayed because of the studied delay.

It is recommended to use the a division into Link effects and Node effects based on the type of vehicle and Business effects based on the type of goods to be able to sum up the effects of a transport chain.

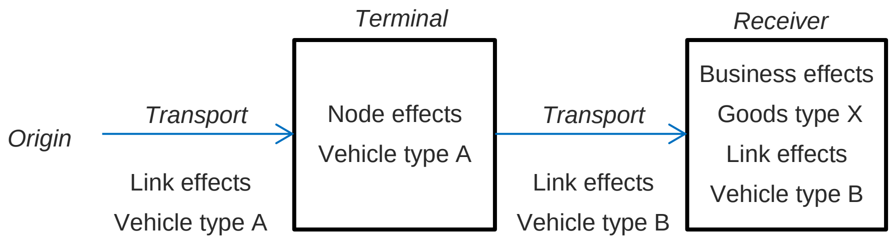

Figure 10: Range of costs

Scale of effects

The size of the effects is determined by the length of the delay and the size of the shipment being delayed.

As previously discussed, it is likely that the effects of a delay will increase with the length of the delay. The effects should therefore be made dependent on the length of the delay where the effects are assigned different costs dependent on the length. Further studies are required to determine if the increased cost should be estimated as linear to time or not. It is likely that the true cost is not linear but rather exponentially increasing. However, as non-linear variables are hard to handle, options could be to use fixed time intervals with different cost levels or to assume linearity.

The effects are also dependent on shipment sizes. It can be argued, as with the lengths of delays, that the effects of delays are not linear to the shipment sizes, i.e. the effects are exponentially greater for larger shipments. However, this effect is to a larger extent situation dependent as what is considered a “small” shipment in one case could be a “large” shipment in another case. It is therefore considered most feasible to use a linear scale, i.e. the effects are the same for each tonne in a shipment.

The size of a shipment could be measured in many units, e.g. tonnes, volume, pallets, vehicles etc. It is recommended to use tonnes since most statistics and the current model use tonnes. A potential option is to use number of vehicles as many of the effects are dependent on vehicle type and delays occur for a whole vehicle. However, tonnes can easily be converted to vehicles by using average load factors why it is considered preferable to use tonnes to be compatible with existing models.

Summary of data structure

The cost of a delay can thus be condensed into five key factors:

1) Standardised delay costs
2) Length of delay in time
3) Size of shipment in tonnes
4) Type of goods
5) Vehicle type

The total costs are determined by taking the effects for the appropriate node or link for the current goods type or vehicle type and length of delay and multiplying this with the size of shipment.

For now we suggest that the goods types and vehicle types are classified according to the Samgods model, for consistency with the rest of the models used for national planning. However, further studies could suggest that other classifications are more suitable for this case.

3.6 Conclusion

The main challenge identified is to estimate the situation dependent characteristics and complexity of the transport chain in a generalised way that can be supported by available input data. The scope of the variables should exclude the large magnitude effects as they are better analysed separately. The range of the costs should focus on the link and node effects and business effects of a delay. This makes it possible to calculate the delay effects of a transport chain by summing up the different variables.

4 Description of the micro-economic model

4.1 Background

Winston, (1979) is usually the starting point when discussing $VTTS$ and valuation of other transport attributes used in cost benefit evaluations of investments involving freight transportation. From an argument that the principal uncertainties in freight transportation was taken care of at the macro level of firms in the form of shareholders diversification of their stock portfolios, Winston used the personal utility of the shipping firms transport manager for studying the mode choice. This approach is similar to a principal-agent approach. However, in a CBA setting, the transport managers' personal utility is less suitable, a derivation from profit maximization of firms would be the natural choice. Winston's formulation has been reworked in a profit maximization setting by Bergkvist (2001), which has been referred to in, among others, Zamparini and Reggiani (2007). Bergkvist's approach consist of a direct first-order Taylor series expansion of the shippers unconstrained profit function, where the profit function is conditioned on a vector of transport attributes and a vector of firm-specific attributes. A drawback with this derivation is that it gives no hints on the suitable functional form for each specific attribute, for example transportation time variability. For passenger transport, the use of so called scheduling utilities[5] (Fosgerau and Karlström, 2010), has made it possible to reach more specific conclusion of the functional form of transportation time variability. There have been proposals, see for example Vierth (2010), to use a similar approach for freight. In a setting like Winston's original approach using the personal utilities of transport managers it may be fairly straight forward to translate the scheduling utilities approach to freight transports. On the other hand, it is less clear for a formulation in terms of profit maximization (since the transport manager maximizes his own benefits, not necessarily the company's profit).

4.2 Micro-economic approach

The method we propose is a cost savings approach applied to individual transports or shipments. Instead of using a first-order approximation of the unconstrained profit function of the shipper, using the cost function obtained by constraining the shippers profit maximization by its production level is more suitable for the proposed method. The data collection will be carried through by following the same individual transports both at the shipper and the haulier. By using cost functions, it

[5] That is, components for the disutility of late and early arrival are included in the individual's utility.

is relatively straight forward to extend the method to this situation. Since transport cost is part of the constrained profit maximization, one important deviation from Bergkvist's approach is that the transport cost will not be a part of the attributes of the transport.

We will focus on the so called transport time, which is the door-to-door time for the goods between the shipper and the receiver, and its variability.[6] The attributes of a transport will be collected in a vector Z which will at least consist of a measure z_v of the variability of transport time and the expected transport time z_{ett}. The end is to measure the total surplus (or loss), $S = \sum_i S_i$ where i denotes a particular consumer or a firm, in society from some change ΔZ in transport attributes. It is assumed that the total surplus can be measured by only considering three of the actors involved in the transport. They are the sending and receiving firms, and the carriers. This assumption will be further qualified below. All three agents are assumed to be profit maximizing firms. To simplify the formulation of the profit maximization problem, the shipper and receiver are assumed to be within the same firm, called the transport buyer. In reality there exist all possible combinations of ownership structures between shippers, carrier and receivers. We need to build a model which is stable in relation to that, but general enough not to drown in case specific issues. Dividing between shippers/receivers and carrier is necessary because of the different types of cost structures.

All entities, except where the agent is obvious, referring to the buyer and the carrier will be superscripted with B and C. To further simplify the expressions, company specific attributes W^B and W^C are suppressed in the production functions. By slightly abusing the notation of the transport attribute vector, all entities related to the transport but not included in the attribute vector will be subscripted with z. The profit functions, π^B and π^C, for the buyer and the carrier in their profit maximization problems are

$$\pi^B(p, w^B, w_z; Z) \equiv \max_{l^B, l_z} p f^B(l^B, l_z; Z) - w^B l^B - w_z l_z, \qquad (1)$$

and

$$\pi^C(w_z, w^C; Z) \equiv \max_{l^C} w_z f^C(l^C; Z) - w^C l^C. \qquad (2)$$

where

f^B,f^C = the production functions of the buyer and the carrier,

l^B,l^C = vectors of input factors for the buyer and the carrier (typically, labor and capital),

Note that when the term delivery time is used in this text, it means the time of delivery of the freight.

p = price of the good produced by the buyer,

w_z = transport price,

w^B, w^C = row vectors of factor prices for the input factors,

l^B, l^C = row vectors of input factors,

Note that $l_z = f^C(l^C; Z)$. The important fact of the profit maximization problem given by (1) and (2) is that the transport attribute Z influences the profit maximization through the production functions of the actors. Changes in the transport attribute will potentially change the utilization of input factors and substitution pattern between them.

From the standard formulation of cost functions, given production levels y^B and y^C for the two actors, the cost functions

$$c^B(w^B, w_z, y^B), \quad c^C(w^C, y^C), \tag{3}$$

where

c^B,c^C = the cost functions of the buyer and the carrier

are solutions to the profit maximization problem (1) and (2) constrained by the given production levels. That is, they are solutions to the following two cost minimization problem:

$$c^B(w^B, w_z, y^B) \equiv \min_{l^B, l_z} w^B l^B + w_z l_z, \tag{4}$$

$$\text{such that} \quad f^B(l^B, l_z; \mathrm{Z}) = y^B, \tag{5}$$

and

$$c^C(w^C, y^C) \equiv \min_{l^C} w^C l^C, \tag{6}$$

$$\text{such that} \quad f^C(l^C; Z) = y^C. \tag{7}$$

where y^B,y^C are given production levels for the buyer and the carrier,

From this, a cost savings approach to estimate the cost functions can be done independently for the buyer and the carrier, without any need to keep track of the same transport for the two actors. This is principally the standard procedure in freight CBA-assessments. However transport price w_z is part of the buyer's cost function. This is a known problem, both to get the actors to disclose price information and the necessity that the prices well enough distinguish for differences in the transport attribute of interest. A further problem is that it is not clear how to combine the information from the cost functions given by (5) and (7) into the total surplus S:

Under perfect competition the buyers cost function itself is enough to estimate the total S. But under less restrictive assumptions it will be necessary to estimate supply and demand function in order to estimate S without double-counting or missing some part of S. However, by extending the definition of the cost functions given by (4) and (5), with an additional constraint it is possible to avoid including transport cost in the buyers cost function. Further, with the extra constraint, it is possible to add the cost functions of both buyer and carrier to get the total surplus S without the need for assumption of market conditions for the actors.

The extra constraint needed is to restrict the profit maximization of the buyer to the production volume of the carrier, which is including the constraint $l_z = y_C$ in the buyer's optimization problem. This adds l_z as an argument to the buyers cost function, and excludes transport volume and price from its cost minimization in (5). The following two cost minimization problems are obtained.

$$c^B(w^B, y^B, l_z) \equiv \min_{l^B} w^B l^B, \tag{8}$$

$$\text{s.t.} \qquad f^B(l^B, l_z; Z) = y^B,$$

$$l_z = y^C,$$

and

$$c^C(w^C, y^C) \equiv \min_{l^C} w^C l^C, \tag{9}$$

$$\text{s.t.} \qquad f^C(l^C; Z) = y^C.$$

For notational simplicity we may change the parameter y^C in the carrier's cost function to l_z. That the transport attribute vector Z is a parameter of the constraints in (8) and (9) will mean that, by the implicit function theorem, it is also a parameter of the two cost functions. Further, by a similar argument, the suppressed parameters W_B and W_C denoting firm specific attributes is also parameters in the corresponding cost functions. The resulting cost functions have the following form.

$$c^B(w^B, y^B, l_z, W^B, Z), \quad c^C(w^C, l_z, W^C, Z). \tag{10}$$

The buyers cost function represents the minimum cost of the buyer given that both its production level and its transport volume are fixed. This assures that it is possible to estimate the cost functions without using transport price. In addition to this it is possible to add the two cost functions to get the total surplus S, without making assumptions on the market conditions for the two actors. Keeping the production level fixed is also motivated from a broader cost benefit perspective. Since production levels (in the Swedish model structure) is fixed both in the forecast and in the VTTS, including it in the VTTV is both inconsistent and not the best way to take it into account.

In order to derive expressions for the surplus S, define the profit functions *conditional* on the quantities y^B and $l_z(= y^C)$, $\bar{\pi}^B$ and $\bar{\pi}^C$ by:

$$\bar{\pi}^B(p, w^B, w_z, y^B, l_z, W^B, Z) = py^B - c^B(w^B, y^B, l_z, W^B, Z) - w_z l_z, \quad (11)$$

$$\bar{\pi}^C(w_z, w^C, l_z, W^C, Z) = w_z l_z - c^C(w^C, l_z, W^C, Z). \quad (12)$$

Specifically, when using profit maximization quantities, y^{*B} and l_z^*, in the conditional profit functions, they coincide with the ordinary profit functions from (1) and (2), that is

$$\bar{\pi}^B(p, w^B, w_z, y^{*B}, l_z^*, W^B, Z) = \pi^B(p, w^B, w_z, W^B, Z) \quad (13)$$

$$\bar{\pi}^C(w_z, w^C, l_z^*, W^C, Z) = \bar{\pi}^C(w_z, w^C, W^C, Z) \quad (14)$$

To somewhat simplify notation in the following let X^B denote the vector (w^B, y^B, l_z, W^B, Z) and X^C denote the vector (w^C, l_z, W^C, Z). Now, consider a change in the vector of transport attribute from Z_1 to Z_2. With the aim of estimating the surplus S from this change and avoiding introducing unnecessary restrictions we assume that all quantities of interest in (11) and (12) may change as a result of the change in the transport attribute. Accordingly, theses quantities are also indexed by 1 and 2 respectively. Then, by using (11) and (12) we may define a *conditional* surplus $\bar{S}$, by[7]

$$\begin{aligned}\bar{S}(p_1, p_2, X_1^B, X_1^C, X_2^B, X_2^C) &= \bar{\pi}^B(p_2, w_{z(2)}, X_2^B) - \bar{\pi}^B(p_1, w_{z(1)}, X_1^B) \\ &\quad + \bar{\pi}^C(w_{z(2)}, X_2^C) - \bar{\pi}^C(w_{z(1)}, X_1^C) \\ &= \left(p_2 y_2^B - p_1 y_1^{\mathrm{B}}\right) - \left(c^B(X_2^B) - c^B(X_1^B)\right) \\ &\quad - \left(c^C(X_2^C) - c^C(X_1^C)\right).\end{aligned} \quad (15)$$

Note that transport price w_z is not in the arguments of $\bar{S}$ since the terms $w_z l_z$ cancels when the conditional profit functions of the buyer and the carrier are added in

[7] The chosen approach is only valid under inelastic demand for *B*s output and perfectly elastic supply of all inputs in (15). For any less restricting assumptions the surplus must be calculated as an integral along equilibrium and profit maximization paths. Confer Just and Hueth (1979) for a more general approach to a vertically structured market. However, the stated assumption is used by the Samgods/Samkalk CBA-system. Hence the restrictive assumption have no practical effects.

the intermediate step of (15). Further, by construction, $\bar{S}$ coincides with the ordinary surplus S when all arguments are given by equilibrium prices and quantities. The contribution in (15) of the term derived from py^B in the buyers conditional profit function is an artefact from the restriction to two actors, both assumed to be firms. Applying the conditional approach successively in a more realistic supply chain, these terms would be cancel out at the firm level, but it would appear for the individual end consumer, and prices and output would be for the consumer end product of the chain. In a CBA application, equilibrium prices and quantities are provided by other subsystems [8] of the analysis system. With the aim of estimate the value of transport time variability, no attention to the term py^B in (15) is necessary.

Let asterisk '*' denote equilibrium prices and quantities. Then, as already stated, we have that

$$\bar{S}(p_1^*, p_2^*, X_1^{*B}, X_1^{*C}, X_2^{*B}, X_2^{*C}) = S. \tag{16}$$

This quantity will be called the *exact surplus* from the change in Z. Note that even if only the transport time variability component z_v is changed, with any additional simplifying assumptions, the complete set of arguments to the exact surplus needs to be calculated.

A realistic exact surplus from a change in z_v is a challenge to evaluate. However, it may be approximated by the gradients of conditional costs $D(c(X^j))$ together with the difference vectors $\Delta X^j = X_2^j - X_1^j$, $(j = B, C)$, since

$$\bar{S}(X_1^{*B}, X_1^{*C}, X_2^{*B}, X_2^{*C}) \approx D(c(X_1^{*B}))\Delta X^{*B} + D(c(X_1^{*C}))\Delta X^{*C}$$

In an actual cost benefit assessment the exact surplus from a change in z_v would rather be approximated by only using the z_v component of the gradients, that is

$$\bar{S}(X_1^{*B}, X_1^{*C}, X_2^{*B}, X_2^{*C}) \approx \left(\frac{\partial c^B}{\partial z_v}|_{X^B = X_1^{*B}} + \frac{\partial c^C}{\partial z_v}|_{X^C = X_1^{*C}}\right)\Delta z_v,$$

or in similar rule-of-the-half like ways. The quantity

[8] Whether explicitly forecasted by the system or only treated in a simplified manner, e.g. held constant.

$$\frac{\partial c^B}{\partial z_v}|_{X^B=X_1^{*B}} + \frac{\partial c^C}{\partial z_v}|_{X^C=X_1^{*C}}, \tag{17}$$

will be called the *value of travel time variability* ($VTTV$). For the moment, it is only possible to state fairly trivial conclusions from (17). One such conclusion is that the total $VTTV$ is the sum of each actor's$VTTV$. This fact is usually implied in discussion on valuation of freight transport attribute, one such example is given by deJong et al. (2004a) Since the supply chain was restricted to three actors, it is only by construction that two actors are contributing in (17). By incorporating more actors from the chain in the restricted cost minimizations (8) and (9), more terms will be added to (17). This issue will be further discussed below.

The expression for $VTTV$ in (17) is completely generic. It will have exactly the same form for any transport attribute in the vector Z or any component of the company specific attributes W^j. The next section will give a more decomposed expression for $VTTV$ (or the exact surplus) which depends on the timings of activities in the involved firms.

From costs for individual transports to cost functions

Transport time variability is a property of a population of transports with identical transport attributes (i.e. with variability excluded). The cost associated with a certain level of transport time variability is the value of the cost function with all other arguments set to specific values.

Under uncertainty, whether induced by transport time variability or uncertainty with respect to other attribute components or arguments of the cost function, it may be assumed that the firms minimize the *expected* cost, hence the minimizations in (8) and (9) should be stated as

$$\begin{aligned} &c^B(w^B, y^B, l_z, W^B, Z) \equiv \min_{l^B} E(w^B l^B), \\ &\text{s.t.} \quad f^B(l^B, l_z; Z) = y^B, \\ &\qquad\qquad l_z = y^c, \end{aligned} \tag{18}$$

and

$$\begin{aligned} &c^C(w^C, y^C, W^C, Z) \equiv \min_{l^H} E(w^C l^C), \\ &\text{s.t.} \quad f^C(l^C; Z) = y^C, \end{aligned} \tag{19}$$

where $E(\cdot)$ is the expectation operator of a random varable. This setting raises a conceptual problem. The actors minimize the expected future costs in their decision problems, while we may investigate already occurred past costs. This requires the assumption that the actors have rational expectations. It then follows that on the average the actors expectation for a situation given by a specific set of arguments to the cost function will coincide with occurred cost under the same set of arguments. Further, the actual minimization in (18) and (19) will not be performed directly. Instead it will be assumed that observed occurred costs will come from cost minimizing actors. In the following let X^C and X^B denote the vector of arguments to the cost function of the buyer and the carrier.

Let l^{*B} denote the cost minimizing quantity of the buyer's input factors, and let K^B denote the occurred cost of all activities that the buyer has performed during a past time period. Then, given X^B and under the assumptions above, rational expectations and cost minimizing behaviour, we have for the buyer that

$$c^B(X^B) = E(w^B l^{*B}|X^B) = E(K^B|X^B). \tag{20}$$

It is for thethe last equality that the assumptions on rational expectations and cost minimizing behaviour are necessary. Similarly, for the carrier, let l^{*C} denote the cost minimizing quantity of its input factors, and let X^H be given, then

$$c^C(X^C) = E(w^C l^{*C}|X^C) = E(K^C|\mathrm{X}^C). \tag{21}$$

Now, for the function K^j $(j = B, H)$ of occurred cost, since we assume that the occurred costs are derived from cost minimizing K^j needs to have the form $w^j l^{*j}$. This may be achieved by record the use of input factors per activity l_k^{*j}, where $k = 1, \ldots, m^j$ index the type of activity. Then, letting fixed costs not attributable to specific actions be denoted by F^j, we get

$$K^j = F^j + \sum_{k=1}^{m^j} w^j l_k^{*j}. \tag{22}$$

To study the influence of transport time and its variability, the timing of activities needs to be incorporated into (22). One way of doing that is to use a vector of right-continuous step functions $N^j(t) = \left(N_k^j(t)\right)_{k=1}^{m^j}$ where $N_k^j(t)$ records the number of times activity k has finished during the time period $[0, t]$. The whole study period is $[0, \tau]$ $(\supseteq [0, t])$. Under uncertainties and the assumption that there is a finite number of jumps of N^j in the finite time-interval $[0, \tau]$, N^j is a multivariate point-process, or more specifically a multivariate counting process (Andersen et al., 1993, chap. 2). Let $N_k^j(t^- t -)$ denote the left-hand limit of $N_k(t)$, that is $\lim_{s \to t, s<t} N_k^j(s)$, then $\Delta N_k^j(t) = N_k^j(t) - N_k^j(t^-)$ is zero everywhere except at the jump points, where $\Delta N_k^j(t) = 1$. If we denote the ith jump point of N_k^j by $T_{k(i)}^j$, then $N_k^j(t)$ may be rewritten as

$$N_k^j(t) = \sum_{i \in \{i: T_{k(i)}^j \le t\}} \Delta N_k^j(T_{k(i)}^j).$$

Now consider use of input factors per activity l_k^{*j} in (22). Rewrite it as a sum of the individual resource usages for each occurance of the activity $l_k^{*j} = \sum_i l_{k(i)}^{*j}$. The $l_{k(i)}^{*j}$ may be highly dependent to the circumstances of the individual occurence of the activity. For example, if the activity is receiving a freight transport, then staff absence may or may not force hiring of replacements, resulting in a varying cost between different occurrences of receiving goods. Hence, it is reasonable to treat $l_{k(i)}^{*j}$ as a random variable. The information contained in $l_{k(i)}^{*j}$ will be collected in continous random processes $l_k^{*j}(t)$ such that $l_k^{*j}(T_{k(i)}^j) = l_{k(i)}^{*j}$. They can be seen as processes continously updating the resource usage of an activity, ready to produce an answer when the activity ends. Now, we have that

$$w^j l_k^{*j} = \sum_i w^j l_{k(i)}^{*j} = \sum_{i \in \{i: T_{k(i)}^j \le t\}} w^j l_k^{*j}(T_{k(i)}^j) \Delta N_k^j(T_{k(i)}^j),$$

and the last part of the above expression is a stochastic integral (with ΔN as a Dirac measure). So we may write

$$w^j l_k^{*j} = \int_0^t w^j l_k^{*j}(s)\, dN_k^j(s).$$

Then

$$K^j(t) = F^j + \sum_{k=1}^{m^j} \int_0^t w^j l_k^{*j}(s)\, dN_k^j(s), \tag{23}$$

is the cost accumulated by firm j during the time period $[0, t]$, and we have that $K^j(\tau) = K^j$. To simplify, let $r_k^j(t) = w^j l_k^{*j}(t)$ and when necessary $R_k^j(t) = \int_0^t r_k^j(s)\, dN_k^j(s)$, then by (20) and (21), we get

$$c^B(X^B) = E(F^B | X^B) + E\left(\sum_{k=1}^{m^B} \int_0^\tau r_k^B(s)\, dN_k^B(s) | X^B\right), \tag{24}$$

and

$$c^C(X^C) = E(F^C | X^C) + E\left(\sum_{k=1}^{m^C} \int_0^\tau r_k^C(s)\, dN_k^C(s) | X^C\right). \tag{25}$$

Focusing for the moment on the latter non-fixed cost terms in of (24) and (25). For simplicity, the conditioning on X^j is for the moment suppressed from the expressions containing expectations. The expectation moves under the summation sign, so we may restrict attention to the expected cost for a specific activity k, that is

$E(\int_0^\tau r_k^j(s)\, dN_k^j(s))$. Now for the expectation of a stochastic integral of a counting process, we have that (Andersen et al., 1993, chap. 2)

$$E\left(\int_0^\tau r_k^j(s)\, dN_k^j(s)\right) = E\left(\int_0^\tau r_k^j(s)\, d\Lambda_k^j(s)\right), \tag{26}$$

where Λ_k^j is the compensator or accumulated intensity of the counting process N_k^j. If the finishing time T_k^j of activity k has a continuous probability distribution, which we will assume in the following, then (26) will have an ordinary integral [9] with respect to time, inside the expectation

$$E\left(\int_0^\tau r_k^j(s)\, dN_k^j(s)\right) = E\left(\int_0^\tau r_k^j(s)\lambda_k^j(s)\, d(s)\right), \tag{27}$$

where $\lambda_k^j(t)$ is the intensity of N_k^j, that is the probability of T_k^j to occur in a small time interval $[t, t+dt]$ given that it has not occurred at t. The expectation and integration is, under fairly general conditions, interchangeable in (27). If we make the conditioning on X^j explicit again, this gives

$$E(R_k^j(\tau)|X^j) = E\left(\int_0^\tau r_k^j(s)\, dN_k^j(s)|X^j\right) = \int_0^\tau E(r_k^j(s)|X^j)\lambda_k^j(s|X^j)\, d(s).$$

The expectation $E(r_k^j(s)|X^j)$ is $E(w^j l_k^j(s)|X^j)$. Since the input price vector w^j is given in X^j and hence non-random it can be moved outside the conditional expectation, giving

$$E(R_k^j(\tau)|X^j) = \int_0^\tau w^j E(l_k^j(s)|X^j)\lambda_k^j(s|X^j)\, d(s). \tag{28}$$

This emphasizes that it is the input factor usage associated with activity k together with the intensity $\lambda_k^j(s)$, for the activity, that determines the conditional running cost of the activity. Substituting (28) into (24) and (25), we get the following expression for the cost function

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[9] In the sense that it is not a stochastic integral over a random process, as is the case with the integral over $\Lambda_k^j(s)$ in (26). However, even though the integral inside the expectation in (27) is not stocastic it is a random variable since $r_k^j(t)$ is a random process and $\lambda_k^j(t)$ may be a random process.

$$c^j(X^j) = E(F^j|X^j) + \sum_{k=1}^{m^j} \int_0^{\tau} w^j E(l_k^j(s)|X^j)\lambda_k^j(s|X^j)\, d(s). \tag{29}$$

Once again leaving the fixed cost aside and concentrating on the running cost in (29), we see from the expression for the conditional surplus in (15) that only activities where the expected resource usage or the intensity is non-constant with respect to changes in X^j, will contribute to a non-zero conditional surplus. Hence, when the aim is to compute the conditional surplus from a particular change in X^j, we can exclude all activities in the cost function (29) which are constant with respect to that change in X^j.

There are two type of activities in (29) that may consume resources for the firm, (1) activities with a *duration* such that the resource usage is a function of the duration, and (2) an *event in time* which other activities depend on, and where deviation from the planned event time may incur additional costs. These two types of activities may of course combine. An activity with a duration may give rise to two important event times, the start time and the finish time of the activity. Freight transports provide a template for both type of activities. For the carrier, a transport consumes both labour and capital roughly proportional to its duration, the transport time. Deviations in both the start and delivery time for the transport are also event times which may incur additional costs to the carrier. For the sending and receiving firm the start and delivery time respectively are for the typical transport, only event time, where the transport time has no or only marginal importance to the sender or the receiver. Apart from these type of transports, there are of course transports where transport time may be critical for the receiver, for example when a replacement part is needed after a machine failure.

4.3 Properties of VTTV

The component z_v of the transport attribute Z denotes a generic parameter for the variability of transport time. In order to have a name for this parameter, let's call it the dispersion of transport time or depending on the context, delivery time.

Let k now be the activity for the buyer to recieve a freight transport, and when considering a carrier, the activity of performing the same transport, then the buyer's and carrier's part of the $VTTV$, denoted $VTTV^j$ $(j = B, C)$, will be

$$VTTV^j = \frac{\partial c^j}{\partial z_v}\Big|_{X^j = X_1^{*j}}$$

To get an understanding of the properties of $VTTV^j$ from these relations, we will study $\frac{\partial c^j}{\partial z_v}$ for the activity k of recieving a transport for the buyer and producing a transport for the carrier. From (29) (continuing to ignore the fixed cost part) and by general properties of derivatives, we have

$$\frac{\partial c^j}{\partial z_v} = \int_0^\tau w^j \frac{\partial E(l_k^j(s)|X^j)}{\partial z_v} \lambda_k^j(s|X^j)\, d(s) \qquad (30)$$
$$+ \int_0^\tau w^j E(l_k^j(s)|X^j) \frac{\partial \lambda_k^j(s|X^j)}{\partial z_v}\, d(s).$$

The derivative in the first term above has been kept outside the expectation, since the expected resource usage may have a derivative with respect to z_v even in the case when $l_k^j(t)$ does not. Equation (30) means that $VTTV^j$ has two distinct additive components, denoted $VTTV_L^j$ and $VTTV_\lambda^j$, corresponding to the first and second terms in (30), we may write

$$VTTV^j = VTTV_L^j + VTTV_\lambda^j. \qquad (31)$$

$VTTV_L^j$ is the contribution to $VTTV^j$ from changed usage of input factors l_k^j as z_v changes, when the intensity λ_k^j is held constant . $VTTV_L^j$ is zero only if all use of input factors are constant with respect to z_v. For $VTTV_\lambda^j$, the intensity λ_k^j completely determines the probability distribution[10] of the transport or delivery time. This means that $VTTV_\lambda$ is the contribution to $VTTV^j$ from a change in probability distribution of the delivery or transport time when the dispersion z_v of that distribution change, and the usage of input factors is held constant.

It is tempting to interpret the case when transport time is completely irrelevant for a receiving firm (discarding issues like capital binding during transport) as an argument in support of the conclusion that the receiver has no value of travel time savings ($VTTS$). However, one important aspect of the intensity in (29) is that it is likely that (expected) transport time is a parameter, explicit or implicit, in the delivery time distribution. Then the receiver will have a $VTTS$, derived from the intensity part of the costcost function, even in the case when the expected cost is constant with respect to transport time. Hence, when considering timing of activities for firms, there will be rather intricate relations between transport time and its variability.

[10] This follows from the uniqueness of the Doob-Meyer decomposition of a counting process (Andersen et al., 1993, p. 73).

Estimating $VTTV$

The chosen route to estimate $VTTV$ will be to estimate the cost function given by (29), then computing $VTTV$ by taking the derivative of the estimated cost function with respect to the dispersion of transport time z_v. This has the advantage that the estimated cost function can be used in calculation of the exact (conditional) surplus, as well as to calculate $VTTV$. As already stated in the preceding section, if we neglect the fixed cost in (29), the costs are additive by activities and we may restrict the studied cost function to only include the transport activity k. How to treat the fixed cost will be further discussed below. Hence, the estimated cost function in this section will be the (running) cost restricted to transport activity k, that is

$$c_k^j(X^j) = \int_0^\tau E(w^j l_k^j(s)|X^j)\lambda_k^j(s|X^j)\, d(s). \qquad (32)$$

The integral is over the firms planning period $t \in [0, \tau]$. There is a choice whether the activity k should denote a recurrent transport of the same type which may occur several times in $[0, \tau]$, or if k denote a specific transport which only occur once in $[0, \tau]$. To simplify the exposition the latter will be assumed, that is k is a specific transport only occurring once. This assumption is equivalent to assume that the transports are independent given X^j. For the estimation method given below on data at the level of individual transport this assumption is rather easily relaxed. However, for the more aggregate estimation methods discussed further below the assumption on conditional independence is likely to be binding. With this definition of k, the intensity for transport k is identically zero before some random time τ_0^j, which for the buyer may be the delivery time of the last transport preceding k and for the carrier it is the starting time of the same transport k. Hence we may restrict the integral in (32) to the time period $[\tau_o^j, \tau]$. By defining k as a single specific transport having one event time, it is possible to estimate the intensity λ_k^j in (32) by methods used for counting processes in survival analysis or reliability analysis. However, by instead using the generalization of a counting process into a so called marked point-process, both $E(w^j l_k^j(s)|X^j)$ in (32) and the intensity λ_k^j can be estimated simultaneously, increasing the efficiency of the estimation.

Now, we have a specific time interval in the integral in (32) for the buyer and the carrier. However, we may move the buyer's starting time τ_0^B, without any essential difficulties (Andersen et al., 1993, p. 82) to the carrier's starting time for the transport τ_0^C. Then both have the same time interval $[\tau_0, \tau]$ for their integrals in (32). During estimation it is also convienient to not having to keep track of the different τ_0s of all observed pairs of buyers and carriers. So, let's translate the time scale so that $\tau_0 = 0$, and remember that $[0, \tau]$ now refers to this resulting time interval. Now, with this transformation, the transport time of the carrier is the same as the delivery time of for the buyer. The upper limit τ is not critical, and since the intensity λ_k^j is identically zero as soon as the transport has finished it has no longer any connection to the planning horizont of the actors in their profit maximizations. Hence, τ can be decided mainly from what is practical during data collection. However it needs to conform to a valid censoring model for the event times of transport activity k. Andersen et al. (1993) contains an extensive discussion on censoring. With this transformation of timescale it is obvious that the buyer and the carrier have the same intensity (though they had that even before the time transformations, since these transformation are such that they cannot change the intensities in any essential way). Hence, since expected transport time z_{ett} may be viewed as an essential parameter in the carrier's transport time distribution, the identity of the carrier's and the buyer's intensity imply that a buyer can have a $VTTS$ even in the case there is no stake in the transport time for the buyer (that is, only the delivery time matters).

The buyer is, in this exposition, identical with both the sender and the reciever of the freight. However the above discussion is solely applicable to the reciever. For a complete estimation of VTTV the sender should be included as well. Then also the starting time of the transport would be modelled as a random process. Since a delayed delivery may be caused by a delayed start of the transport, these two events should preferably be estimated jointly in a common model. The proposed model for estimation can be extended to such a situation by treating the start and delivery times as two transition times between different states. The model specified below and cited from Scheike (1994) is explicitly designed to model such dependencies, Martinussen and Scheike (2006) also discusses state models to some degree, and the whole subject is thoroughly covered in Andersen et al. (1993). This may be further extended to consider a multipart transport chain given by changes in mode and transhipments at terminals. However, to avoid an unnecessary complex exposition, neither of these important extensions is further discussed. The interested reader is kindly refered to the cited litterature.

Before discussing estimation, we may note that input factor prices w^j are in both the response variable $w^j l_k^j$ and the explanatory variables X^j in $E(w^j l_k^j(t)|X^j)$. In order to be able to estimate the input factor demand relations implied by profit maximization, it is reasonable to estimate $E(l_k^j(t)|X^j)$ (which is a vector, since l_k^j is a vector) and keep w^j among the explanatory variables X^j, and convert resource usages to cost afterwards by multiplying with prices w^j. Likewise integration of costs over $[0, \tau]$ may be performed afterwards. If a parametric estimation of the intensity is performed, this is a necessity, while a non-parametric estimation gives the option of a direct estimation of the integral. For the intensity λ_k^j, as already concluded, it is the same for both the buyer and the carrier and the index j may be dropped. Further, without any a priori restriction, we should condition λ_k on both X^B and X^C. In total this gives the following quantities to estimate

$$E(l_k^B(t)|X^B), \tag{33}$$

$$E(l_k^C(t)|X^C), \tag{34}$$

$$\lambda_k(t|X^B, X^c). \tag{35}$$

Now with these preliminaires, the expected resource usage in (33) and (34) is modelled as a multivariate regression functions m^j with the same number of components as l_k^j, and taking X^j $(j = B, C)$ and time t as variables, that is

$$E(l_k^B(t)|X^B) = m^j(X^B, t; \beta_1), \tag{36}$$

$$E(l_k^C(t)|X^C) = m^j(X^C, t; \beta_2), \tag{37}$$

where β_1 and β_2 are vectors of regression coefficients.

Estimation data have observations indexed by i for each event time (delivery time or transport time). The observations are tuples $(T_i, l_{ki}^B, l_{ki}^C, X_i^B, X_i^H)$, where T_i is the event time, X_i^j is the vector of conditioning variables from the cost functions of the firm having the ith event time, and l_{ki} is the estimate of resource usage associated with actor j for the transport having event time T_i. To estimate the regression functions (36) and (37) jointly with the intensity (35), on these data, a regression model may be defined as

$$l_{ki}^B = m(X_i^B, T_i; \beta_1) + \varepsilon_i, \tag{38}$$

$$l_{ki}^C = m(X_i^C, T_i; \beta_2) + \varepsilon_i, \tag{39}$$

$$T_i \sim \lambda_k^j(t|X_i^B, X_i^C; \theta, \beta_3), \tag{40}$$

where '$\sim$' in (40) denotes that event times T_i are generated by the intensity process λ_k (derived from the underlying marked point-process generating (38), (39) and (40)), and θ is in the parametric case a parameter vector determining the probability distribution with intensity $\lambda_k(t|X_i^B, X_i^C; \theta)$, and β_3 is a vector of regression parameters for regressing θ on the explanatory variables X_i^j. In the non-parametric case, θ is a vector of nuisance parameters.

A parametric approach for the joint estimation of (38), (39) and (40) is given in Scheike (1994), which is based on a conditional least squared estimation. A non-parametric approach based on an extension of Aalen's additive hazard regression, is given in Martinussen and Scheike (2000) and Martinussen and Scheike (2006). Both the cited parametric and non-parametric models needs to be extended to multi-variate regression, which is the case here, since they are presented as univariate only model. However, going from univariate to multivariate regression presents no new estimation problems.

A non-parametric approch to estimating (32) may be appropriate when the aim is to estimate the exact conditional surplus. Such situation could be interesting considering that basically no existing freight forecast system delivers any forecast of transport time dispersion parameters z_v. Then an exact conditional surplus may be computed from cost functions, obtained by estimating (38), (39) and (40) with z_v excluded from X_i^j, but including expected transport time z_{ett} and maybe transport distance in X_i^j, as computed by the forecast system (e.g. the Samgods-system). Cost functions estimated by such a procedure, could be seen as implicitly including $VTTV$ together with other trip characteristic valuations, through the non-parametric estimates, together with the included regression variables in (38), (39) and (40). Note, that methods based on Aalen's additive hazard regression, though non-parametric, admits the inclusion of regression variables. Hence, the approach is suitable for counter factual scenario forecasting.

When estimating $VTTV$, the situation is different, the derivative with respect to z_v will be computed from the estimated quantities. Hence we would like both the expected resource usage and the intensity to be explicitly parametrized with the dispersion z_v. Since expectected transport time is an essential parameter in the transport activity intensity, it is preferable to also choosing a parameterisation with z_{ett} as a parameter. This could be achieved by using a two-step approach where z_v and z_{ett} is first estimated from the sample and then used as explanatory variables among the other variables, either in the non-parametric models, described above, or in a traditional parametric survival analysis estimation. However, this will be an inefficient estimation dependent on having a rather large number of repeated observation for each unique vector of explanatory variables X^j. Further, in a typical transport time distribution, both expected transport time z_{ett} and dispersion z_v share common factors in form of parameters of the distribution. Hence, there will likely be multi-collinearity problems in the estimation. Therefore, an attractive approach is to reparameterise the transport time distribution to have z_v and z_{ett} as parameters, since such an approach could be designed to not depend of having repeated observations in the sample. For example, if the original parameters of the distribution is θ, as in (40), and if g is a link function such that

$$\theta = g(z_{ett}, z_v). \tag{41}$$

Then we may estimate the following transformed version of (38), (39) and (40)

$$l_{ki}^B = m(\bar{X}_i^B, \mu, \sigma, T_i; \beta_1) + \varepsilon_i \tag{42}$$

$$l_{ki}^B = m(\bar{X}_i^H, \mu, \sigma, T_i; \beta_2) + \varepsilon_i \tag{43}$$

$$T_i \sim \lambda_k(t|\theta = g(f(\bar{X}_i^B, \bar{X}_i^H; \beta_3))), \tag{44}$$

$$(\mu, \sigma)' = f(\bar{X}_i^B, \bar{X}_i^H; \beta_3), \tag{45}$$

where $\bar{X}_i^j$ is X_i^j with z_{ett} and z_v excluded. It follows from (44) and (41) that f is a link function for (z_{ett}, z_v). Hence, both l_{ki}^j and λ_k may be seen as functions of (z_{ett}, z_v). A $VTTV$-function may then be constructed by formally taking the derivative of the cost functions with respect to z_v, with z_v viewed as a placeholder. Then get $VTTV$ by evaluating the derivative with (z_{ett}, z_v) substituted by $f(\bar{X}_i^B, \bar{X}_i^C \beta_3)$, followed by computing the integral.

4.4 Estimating VTTV on aggregate or marginal data

The data used for estimation in the preceeding section is at the lowest level where the model can make use of the data, that is, at the level of individual transports with corresponding information on associated costs of the actors activities, transport and firm characteristics. That has the obvious advantages in terms of estimation efficiency, attaining consistency and avoiding bias in estimates. However, collecting such data is a demanding task. A reasonable estimate is that only a fraction of the total data set will be on that low level form. Therefore, it will be of interest to discuss estimation on aggregate and marginal data.

For intensities there is a rather well developed theory on how to treat different forms of aggregation of data. The most extreme form of aggregation in time is to replace the event times T_i with indicators for if T_i occurred before or after a specified point in time, which in this case could be for example delayed less than eight hours. Models for this type of aggregation of data is often called current status models, see Lin et al. (1998) for an example of such an approach. Current status data aggregate data into two groups, aggregation into more groups is of course also possible to model, Aranda-Ordaz (1983) provide an example of such an intensity model. There is also possible to combine differently grouped data in a joint estimation of intensities.

However there are no models for the joint estimation of intensity and regression equations as in (39)-(45). This forces a two-step approach where the intensities are estimated in the first step, in order to provide estimates of z_{ett} and z_v for the subsequent regression estimation of expected resource usage. Using grouped data for the regression of expected resource usage corresponds to a model with measurement errors, which are likely to produce biased estimates of parameters. In order to reduce these biases a linear specification which explicitly models the measurement error is preferable.

4.5 Dependencies

The cost functions to estimate, given by (32), has two components, the expected cost as a function of transport time (or delivery time) and the intensity of the transport time probability distribution. In order to calculate VTTV, both these components will be estimated as functions of the dispersion/variability of the transport time z_v. Estimating the intensity is basically an empirical question. The critical entity from a freight transport or logistics point of view is the estimation of the expected cost functions. The resulting VTTV will depend on which costs are included in the estimations. Which cost to include in the expected cost functions is thoroughly covered in the preceding chapter. Note that it may be favourable to assume specific time dependence for the expected costs when using the proposed two-step estimation approach for aggregated data. This is also discussed in the preceding chapter.

5 Data collection test

Based on the conclusions in chapter 3, a list of attributes describing the cost-driving effects of delays, and the related costs, has been extracted. Only variables connected to the range of costs defined in section 3.5 have been included in the list. The variables have been sorted into three categories

1. Values to try to collect through surveys and interviews
2. Values to be estimated from other sources, e.g. ASEK, Samgods, other models
3. Values judged not possible to include currently; further development

In this project, a small-scale test to collect data included in category 1 has been made for a number of transport relations. For details on the variables and the form used, see Appendix 2: Data collection test – variables

5.1 Test group

A form was designed and tested on three transport buying companies in the project's reference group: Coop, SSAB and Stora Enso.

Coop is one of Sweden's major grocery retail trade companies (accounting for approximately 20 % of the grocery retail sector)[11]. Coop has its own logistics department, Coop Logistik, organising the distribution of goods from producers/wholesalers to the stores via a number of terminals in Sweden, using both train and truck transport.

SSAB EMEA (Europe, Middle East and Africa) produces quenched and tempered plate, high strength steels and ordinary strip products. The production facilities for SSAB EMEA are in Luleå, Oxelösund and Borlänge.[12] The production generates large and heavy volumes of inputs as well as outputs, transported mainly by train and ship.

Stora Enso produces paper, biomaterials, wood products and packaging boards.[13] The Swedish production units are located in different parts of the country. Raw material is being transported from the forest to the mills and products are spread over the world. Trucks, trains as well as ships are used for transports.

Complementary information was also collected from one freight train operator, Green Cargo, and a haulier, Alwex.

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[11] https://www.coop.se/Globala-sidor/In-english/ 2013-07-01

[12] http://www.ssab.com/en/Investor--Media/About-SSAB/SSAB-pa-90-sekunder/SSAB-EMEA-/ 2013-07-01

[13] http://www.storaenso.com/ABOUT-US/MILLS/Pages/stora-enso-mills.aspx 2013-07-01

5.2 Method

The transport buying companies were asked to single out up to four typical transport chains and describe them using the form designed for the purpose (see appendix). They were asked to present the effects of delays, based on real cases or estimations in the case no real data was available.

Naturally, the responding organisation does not have all the information asked for. For parts of the data other companies have to fill in the gaps, e.g. train operators or hauliers have more information on the amount of over-time working hours for drivers caused by a delay of two hours in the leg preceding their transport, than the transport buying company has.

It was high-lighted that the purpose of the test was *not* to derive exact values, but to investigate whether the requested type of data is available or not.

After the form was sent to the companies, interviews were carried out in order to discuss the outcome. Which data was available? Were the answers based on real cases or estimated? Was it possible to get hold of the information using a reasonable amount of resources? Was the structure and purpose of the form clearly described?

5.3 Results

Because of the small number of respondents in this test, it is impossible to draw any general conclusions on the availability of the requested type of data. In this section a brief description on the most important findings from the test is given.

There are large differences in the availability of data and statistics on delays between the responding companies. None of the transport buying or transporting companies taking part in the test have any statistics of the requested kind ready for use, but in some cases it would be possible to combine different data sets in order to make the estimations of the costs. The trend seems to be that more and more data on transport quality and related costs is being logged by companies in all parts of the transport chain e.g. in order to get compensated for the costs from the responsible part, to increase the level of service to the clients or to evaluate the performance of sub-contractors.

For the transporting companies, the main costs related to delays and disturbances seem to be staff costs, at least for delays with magnitude of a couple of hours. The ordinary working hours are extended, or personnel have to work over-time which causes higher costs. Over-time work is being logged in systems, but is not always possible to associate to different causes (delays or other) and certain transport relations. Sometimes stand-in of extra staff causes additional fixed costs, e.g. travel costs for taking a new driver to a delayed train. This potential type of cost is not included in the current version of the form but should be taken into account in the future.

For train transports, the number of wagons and locomotives included in the train also has impact on the cost per hour for the vehicle – this information could also be added to the form.

When a railway section is blocked for some reason, trains have to be re-directed to other routes. The cost for this is harder to estimate and it is associated not only with longer working hours and late delivery, but also with e.g. the use of more electricity (if the total transport distance is longer), additional infrastructure fees.

It has been pointed out that the possibility, and therefore the cost, to find stand-in personnel and/or vehicles, could differ much for small and large hauliers and train operators. Therefore companies of different sizes have to be included in the main study.

An issue that is not covered by the form in its current version, is that a delayed train could cause not only a late delivery of goods, but also a lack of empty wagons for the next delivery, if the train arrives late also on the return trip.

For some types of goods, large disturbances in the train traffic can be handled by using alternative vehicles, such as trucks, ships or planes. In the form the related costs are described by naming the type of vehicle used, and the extent to which it is being used (vehicle-hours). The form should be updated with the option of air plane, which is currently not included. Also, it has been pointed out that the main cost associated with replacing a train transport with sea transport, is not the hourly cost for the vehicle, but the fixed cost for finding a ship and arranging the transport. This form should be adjusted to cover also this type of cost.

The cost for late deliveries at the receiver is hard to estimate for some industries, since the main problem seems to be damaged customer relations and lost business, but for others it is possible to estimate an average cost per hour.

Another type of cost caused by delays is delivery quality shortcomings. When a delivery is late to a terminal, on-time delivery to the receiver is sometimes prioritised over quality control routines. Furthermore, stress causes more mistakes in the handling of goods. The effect can be missing goods in the delivery or that the wrong goods go to the wrong place. However, this type of cost is hard to estimate.

Coop was able to make estimations of the costs in stores caused by late deliveries. They also have logs for all distribution transport and the delivery time for every shipment to every store. However, most goods distributed to the stores, have travelled a long way and been transhipped a number of times before loaded on the distribution vehicle. In some cases, the delivery from a main terminal to a distribution terminal could be delayed and cause extra costs for the terminal operator to catch up in order to deliver on-time to the store. Extra staff costs at the terminal can also be logged over time. The challenge will then be to combine these two data sets in order to estimate all costs caused by a delay at a certain stage of the transport.

Even though the form in its current version could be difficult to get an overview of and to understand how it is supposed to be filled in, all correspondents well understood the purpose and the idea behind it after a short introduction. It should be pointed out clearly that the idea is to choose one or several typical transport chains, and not try to cover all possible cases.

5.4 Ideas for full-scale data collection

A future full-scale data collection has to begin with carefully designing the survey and then testing it by a real pilot test. The relevant questions to ask will differ much depending on the characteristics of the transport relation studied in every single case. Therefore the survey should be automatically coded to adjust the form after the initial description of the transport relation, e.g. the number of legs and transhipments in the transport chain, the transport modes involved and the type of goods transported.

All respondents will not be able to provide all the requested data. But according to the results from this test, it does not seem impossible that different responding companies can provide different kinds of data and thus fill in the gaps for each other. The study has shown that the data is available; however a key issue remains to convince companies to share their data. The next stage of the study will show whether this succeeds or not – e.g. by conducting a pilot test before the full-scale study is started. The result will of course depend heavily on what kind of data collection methods that are available, the usability of forms etc.

We suggest that some variables needed to estimate the costs should be modelled or taken from sources such as ASEK or Samgods, rather than being included in the data collection, for example lorry costs (see section “Appendix 2: Data collection test – variables” in the appendix). The reason for this is transparency and possibility to compare calculations to other parts of the CBA system.

The railway system and the trains using it constitute a complex system for which effects of delays and related costs could be complicated to derive. If a pilot test for a full-scale data collection would indicate that surveys and interviews are not suitable for this type of cost estimations, an option could be to estimate these costs (or some of them) using a model system. As a part of this project, the operational extra costs caused by delays for a number of different train transports, have been calculated using the model TSDA (Transport System Design and Analysis, Transrail). The results are presented in Appendix 3.

6 Conclusions

The consequences of major delays vary widely between different customers. While delays in passenger traffic are usually measured in minutes, demands regarding freight traffic vary from minutes up to several days. In a survey of freight customers' values, 9% of the companies had additional costs for delays of less than one hour's duration while 45% had additional costs for delays of 4-6 hours and 40% for delays of a day or more. Freight traffic's diurnal rhythm where products are often manufactured during the day and transported overnight is of great importance but sensitivity to disruptions varies with the type of product. Certain products such as perishable goods and newspapers become worthless if they do not arrive on time while for other products like iron ore and timber a few days' buffer stocks may exist.

In this report, possible effects arising from delays in freight transport have been identified and categorized. Effects have been divided into logistics effects (arising at links or nodes), business effects and system effects. The different costs related to these effects can be condensed into five key factors:

1) Standardised delay costs
2) Length of delay in time
3) Size of shipment in tonnes
4) Type of goods
5) Vehicle type

For now, the goods types and vehicle types are suggested to be classified according to the Samgods model, for consistency with the rest of the models used for national planning. However, further studies could suggest that other classifications are more suitable for this cause.

Most of the identified costs are judged to be possible and feasible, to estimate in the current model and some of them not. The main result from this part is a clear structure for different costs, assigning them to different parts of a transport relation and thus avoiding including the same costs twice. The structure also defines the boundaries for what to include in VTTV by introducing the scope of variables, range of costs, and scale of effects. The scope represents the types of disturbances considered, the range the costs included and the scale the size of the delay. The scope of the variables should exclude the large magnitude effects as they are better analysed separately. The range of the costs should focus on the link and node effects and business effects of a delay. This makes it possible to calculate the delay effects of a transport chain by summing up the different variables.

The main challenge identified is to estimate the situation dependent characteristics and complexity of the transport chain in a generalised way that can be supported by available input data.

The proposed method to estimate VTTV is basically a cost-savings approach. Two distinguishing features of freight transports is that (1) several actors are influenced by a change in transport time variability or other attributes of transports, and (2) a freight transport is an intermediate product. This may double count costs related to VTTV but also that important costs get excluded from the estimation. To address this question a microeconomic derivation, from profit maximization, was performed of cost functions for sending and receiving firms together with the carrier (transport company). The derivation showed that it is necessary to use a non-standard form for the cost functions of the actors. The most notable difference is that transport price should be excluded from the cost functions. The combined VTTV for the three actors was derived as a sum of the derivative of their cost functions with respect to transport time variability. Though the sending and receiving firm together with the carrier has been identified in the literature as the major stakeholders for the value of changes in transport attributes, we have not found any formal derivation of how to actually combine their individual valuations.

Delays imply that there are uncertainties in actual transport times. Hence, the firms must perform their cost minimization with the respect to *expected* future costs. A method has been presented for inferring actors cost functions, obtained from minimization of expected costs, from observed actual cost data. These cost functions can then be estimated as functions of transport time variability (e.g. its standard deviation). Then taking derivatives gives the estimated VTTV. It is shown that the obtained VTTV is a sum of two distinct effects, (1) changes in the time-dependency of the expected cost, and (2) changes in the probability distribution of transport time. This probability distribution is represented as a so called intensity. There is established methods for estimating intensity models, which will be used in the VTTV estimation

A small test for collecting data has been made. The test was not extensive enough to draw any real conclusions on the availability of the data needed or the valuation, but the preliminary results suggest that all respondents will not be able to provide all the requested data. But it does not seem impossible that different responding companies can provide different kinds of data and thus fill in the gaps for each other. The data seem to exist; however a key issue remains to convince companies to share their data. The next stage of the study will show whether this succeeds or. The result will of course depend heavily on what kind of data collection methods that are available, the usability of forms etc. A future full-scale data collection has to begin with carefully designing the survey and then testing it by a real pilot test.

In the analysis of major traffic interruptions in the railway's freight traffic between 2000 and 2013 carried out in this report, it was found that an average of 2.5 interruptions a year lasted 5 days and affected approximately 50 freight trains. 2/3 of the operations were handled with diversions. Information provided by a large transport buying company also confirms the picture given by the survey of major traffic interruptions in Sweden. These appear to have increased in particular after

2005, mainly for two reasons: derailments and extreme weather conditions. Derailments have increased as a consequence of increased traffic and thereby increased wear and backlogged maintenance. The extreme weather conditions have increased due to the climate crisis.

Sensitivity also varies with where in the value added chain transportation takes place and is generally greater the closer to the end customer the products are in the transport chain.

The question is whether it is possible to develop general methods for all situations. Socio-economic calculations are usually used to prioritise investments and calculations for maintenance measures are seldom used. It is important that better calculations to value maintenance measures are developed. Regarding the effects of extreme weather conditions, it is by no means certain that there is any point to developing general methods; they might possibly need to be made in each individual case. When it comes to winter preparedness this is for example very much a matter of organisational measures.

In this report, a method for calculating VTTV is outlined. It is supported by a theoretical framework that also provides a basis for further development of CBA for freight transport, not only concerning variability of the transport time. In order to obtain actual new transport time variability values to be used in CBA, a full scale data collection has to be made. The main challenge will then be to convince businesses to share their information on how their operations are affected by delays, structured in a way that is useful for the calculations.

Even when new VTTV values have been calculated, methods for estimating the effect of different infrastructure measures on the variability of the transport time need to be developed before complete CBAs for freight transport, regarding also the reliability of the transport system, can be carried out.

Bibliography

Andersen, P., Kragh, O. Borgan, R. Gill D., and N. Keiding (1993). *Statistical Models Based on Counting Processes*, Springer-Verlag, New York.

Anderson, S.; Browne, M. (1992). *An analysis of future developments in the use of combined road rail transport by shippers.* Proceedings of the WCTR conference, Lyon.

Aranda-Ordaz, F., J. 1983. *An extension of the proportional-hazards model for grouped data*, Biometrics, **39**,109–117.

Berdica, K.; Jäppinen, J.; Ohnell, S.; Ottoson, M.; Stjärnekull, M. (2005). *Marknadsstudie av potential för intermodala väg-järnvägstransporter- Attityder och värderingar*. Solna, Transek AB

Bergkvist, E. (2001). *Freight transportation — valuation of time and forecasting of flows,* Ph.D. Thesis, Umeå University, Umeå

Bickel, P., A. Burgess, A. Hunt, J. Laird, C. Lieb, G. Lindberg, and T. Odgaard, (2005). *State of the Art in Project Assessment, HEATCO (Developing Harmonised European Approaches for Transport Costing and Project Assessment) Deliverable 2* (Stuttgart: IER)

Björklund, M. (2002*). Environmental Considerations when Selecting Transport Solutions – A contribution to shippers' decision process*. Licentiate dissertation, University of Lund. Lund

Björklund, M. (2005). *Purchasing practices of environmentally preferable transport services: guidance to increase shipper considerations*. Doctoral Dissertation, University of Lund, Lund.

Bolis, S., Maggi, R. (2003). *Logistics Strategy and Transport Service Choices: An Adaptive Stated Preference Experiment*. Growth and Change, 34(4), 490-504.

Bruzelius, N. (2001). *The Valuation of Logistics Improvements in CBA of Transport Investments: A Survey*. Report to the SAMGODS group, SIKA

Chiara, B. D., Deflorio, F., P.; Spione D. (2008). *The Rolling Road between the Italian and French Alps: Modeling the Modal Split*, Transportation Research Part, 44, p. 1162 – 1174

Danielis, R., Marcucci, E. (2007). *Attribute cut-offs in freight service selection.* Transportation Research Part E: Logistics and Transportation Review, 43, 506-515

Danielis, R., Marcucci, E., Rotaris, L. (2005). *Logistics managers´stated preferences for freight service attributes*. Transportation Research part E, 41(3), 201-215

de Jong, G., S. Bakker, M. Pieters, and P. Wortelboer-van-Donselaar. (2004a). *New values of time and reliability in freight transport in the Netherlands*, Association for European Transport

de Jong, G., E. Kroes, R. Plasmeijer, P. Sanders, and P. Waremius. (2004b). *The value of reliability*, Proceedings of the European Transport Conference de Jong, G., M. Kouwenhoven, E. Kroes, P. Rietwald and P. Warffemius, (2009) *Preliminary Monetary Values for the Reliability of Travel Times in Freight Transport*. EJTIR 9(2), June 2009, pp. 83-99

Dinwoddie, J.; Vandewal, M. C. J. (2007). *Multimodal freight policy; practitioners perceptions in the Southern Netherlands*. Proceedings of the WCTR conference, Berkeley

Eliasson, J., Lundberg, M., (2011). *Do Cost-Benefit Analyses influence transport investment decisions?*, Transport Reviews: 1-20

Engström, R. (2007). *Future Competitive Advantages of the Railway in Sweden.* Proceedings of the NOFOMA conference, Reykjavik

Flodén, J., Bärthel, F. and Sorkina, E. (2010). *Factors influencing transport buyers' choice of transport service - A European literature review,* WCTR 2010 Lisbon, July 11-15

Fowkes, A.S., Nash, C.A., Tweddle, G. (1991). *Investigating the Market for Intermodal Freight Technologies*. Transportation research part A, 25(4), 161-172

Fosgerau, M. and A. Karlström. (2010). *The value of reliability*, Transportation Research Part B: Methodological 44, no. 1, 38–49

Fridstrom, L; Madslien, A. (1995). *Engrosbedrifters valg av transportlosning*. TØI rapport, 299

Golias, J.; Yannis, G. (1998). *Determinants of combined transport's market share*. Transport Logistics, 1 (4), 251-264

Hellgren, J. (1996). *Measuring transport quality in Line-based road traffic*. Licentiate dissertation, Chalmers University, Gothenburg

Just, R., E. and D. Hueth L. 1979. *Welfare measures in a multimarket framework*, The American Economic Review 69, no. 5, 947–954.

Laitila, T; Westin, K. (2000). *Miljöhänsyn vid val av godstransportör*. Umeå: Umeå universitet.

Lammgård, C. (2007). *Environmental Perspectives on Marketing of Freight Transports*. Doctoral Dissertation, School of Business, Economics and Law, University of Gothenburg, Gothenburg.

Lin, D., Y., D. Oakes, and Z. Ying. (1998). *Additive hazards regression with current status data*, Biometrika 85, no. 2, 289–298

Ludvigsen, J. (1999). *Freight Transport Supply and Demand Conditions in the Nordic Countries: Recent Evidence*. Transportation Journal, 39(2), 31-54

Lundberg, S. (2006) *Godskunders värderingar av faktorer som har betydelse på transportmarknaden, Licentiatavhandling [Freight customers' valuation of factors of importance to the transportation market],* KTH, TRITA-TEC-LIC 06-001

Maier, G., Bergman, E.M., Lehner, P. (2002). *Modelling preferences and stability among transport alternatives*. Transportation Research Part E: Logistics and Transportation Review, 38(5), 319-334

Martinussen, T. and T. Scheike H. (2006). *Dynamic Regression Models for Survival Data*, Springer, New York

Massiani, J. (2008). *Can we use hedonic pricing to estimate freight value of time?*, EERI Research Paper Series 8/2008, EERI, Brussels

McKinsey (2010) *Utredning Järnväg Vinter*

Posten. (2008). Nordisk Logistikbarometer. Posten

Punakivi,M., Hinkka, V. (2006). *Selection Criteria of Transportation Mode: A Case Study in Four Finnish Industry Sectors*. Transport Reviews, 26(2), 207-219

REORIENT. (2007). *Demand and supply structures for intermodal (rail-based) and single modal (all truck) freight supply solutions*. REORIENT Deliverable D6.1

Rohani, F., Lumsden, K.R. (1998). *The influence of future demands on transport companies*, Paper published in Proceedings of NOFOMA '98, Helsinki, Finland

Scheike, T. H. (1994). *Parametric regression for longitudinal data with counting process measurement times,* Scandinavian journal of statistics, 21(3) 245–263

SIKA. (2002). *En hög transportkvalitet för näringslivet*. SIKA Rapport

SOU 2010:69 *Förbättrad vinterberedskap inom järnvägen [Better winter preparedness on the railway],* Swedish Government Official Reports

TÅG magazine, 2000-2013.

Trafikverket (2012). *Samhällsekonomiska principer och kalkylvärden för transportsektorn: ASEK 5 (Kapitel 7: Tid och kvalitet i persontrafik).* Trafikverket, Borlänge

Vannieuwenhuyse, B., Gelders, L., Pintelon, L. (2003). *An online decision support system for transportation mode choice*. Logistics Information Management, 16(3), 125-133

Waidringer (1999) - *Port logistics from a network perspective; A generic model for port terminal optimisation*, Report 41, Dept. of Transportation and Logistics, Chalmers University of Technology, Göteborg, Sweden.

Waidringer (2001) - *Complexity in Transportation and Logistics Systems: An integrated approach to modelling and analysis*, Report 52, Dept. of Transportation and Logistics, Chalmers University of Technology, Göteborg, Sweden.

Widlert, S. (1990). *Godskunders värderingar*. Transek AB, Solna

Widlert, S., Lindstedt, U. (1992). *Godskunders transportmedelsval*. Rapport VV 1992:25, Vägverket, Borlänge

Vierth, I. (2010). *Valuation of transport time savings and improved reliability in freight transport in cost benefit analyses—pre-study*, VTI rapport 683, VTI, Linköping

Vierth, I., Nyström, J. (2013). *Godstransporter och samhällsekonomiska kalkyler [Freight transportation and socio-economic calculations]*, VTI notat 3-2013

Winston, C. (1979). *A disaggregated qualitative mode choice model for intercity freight transportation*, Ph.D. Thesis, MIT, Cambridge

WSP Analys & Strategi (2012*) Järnvägsnätet och godstrafikens behov – underlag för projektansökan*

Zamparini, L., A. Reggiani. (2007). *The value of travel time in passenger and freight transport: an overview*, Policy analysis of transport networks (M. van Geenhuizen, A. Reggiani, and P. Rietveld, eds.), Ashgate, London, 2007, pp. 145–161

Zhang, A., A. E. Boardman, D. Gillen, W.G. Waters II. (2004). *Towards Estimating the Social and Environmental Costs of Transportation in Canada. A report for Transport Canada.* Centre for Transportation Studies, The University of British Columbia, Vancouver

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Appendix 1: Major traffic interruptions on Sweden's railways 2000-2013 and their impact for transportation customers

Background

In this report, methods of calculating the consequences of delays have been discussed and developed. Delays in passenger traffic are usually calculated in minutes while delays in freight traffic are often calculated in hours. In recent years, major disruptions and interruptions in the railway system lasting one or more days have been increasingly common due among other things to extreme weather conditions resulting from the climate crisis. Major traffic interruptions on the railway can have serious consequences for trade and industry if they mean that important links are blocked. The question of their socio-economic consequences and measures to mitigate their effects has then come to the fore.

No overall statistics have been found on major traffic interruptions. KTH has therefore made a survey of these interruptions between 2000 and 2013.

Aim

The aim was to draw up a compilation of significant traffic interruptions on the railway and shed light on their causes, their extent and their consequences for freight traffic.

Significant traffic interruptions in this context are interruptions or disturbances in the traffic lasting one or more days and that affect several trains. A train that derails on a line, a passing line or a branch line and that does not affect other trains is not included but on the other hand a train that derails on the line or trees falling onto the tracks that result in a complete standstill.

Method

Several sources have been used, to begin with searches on the web and in the press. The primary source with the most complete information proved to be a magazine called TÅG (Trains). TÅG is a monthly magazine for train enthusiasts and contains relatively detailed information about all major events and accidents. In some cases, reports from the National Accident Investigation Authority, the Emergency Services and the Swedish Civil Contingencies Agency have been used.

The following details were included in the survey:

- Time, from (date) – until (date)
- Duration (number of days and number of hours)
- Location
- Type of event
- Cause

- Sections closed
- Diversion via
- Geographical effect
- Number of freight trains affected (estimate)
- Categorisation of cause
- Possible measures to avoid interruption
- Possible measures to mitigate the consequences of the interruption

Delimitation

The analysis comprises interruptions in Sweden. Interruptions in other countries and in ferry traffic may also affect transportation for Swedish trade and industry. Impact on passenger traffic is not included. The period studied is from January 2009 until April 2013 inclusive. Three major interruptions that occurred in May 2013 are not included.

Findings

A full compilation of all data can be found in a report that is only available in Swedish. A summarising description and analysis follow below.

During the period in question, 32 major traffic interruptions were identified up until March 2013. These comprised a total of 160 days or 3,525 hours. See Table 1. At least 1,578 freight trains were affected (this figure is incomplete). An average of 2.5 interruptions a year thus lasted 5 days and affected approximately 50 freight trains. 2/3 of the operations were handled with diversions.

Table 1: Extent of major disturbances and traffic interruptions 2000-2013

Total, 2000-2013				***Average per year***			
Number of interruptions	Number of days	Number of hours	umber of affecte freight trains*	Interruption per year	Days per interruption	Hours per interruption	Freight trains per interruption
32	160	3 525	1 578	2,5	5,0	110	49

*) Not complete

Almost 50% of the interruptions lasted one or two days and slightly less than 30% lasted more than a week. The number of traffic interruptions is relatively evenly spread over the years with the exception of a peak in 2000 as a result of torrential rain and a trough between 2001 and 2004 with few days of interruptions. The number of days of interruptions shows a slightly declining trend.

The causes of the interruptions are shown in Figure 1 and Table 2. 44% of the interruptions were caused by derailments and 31% were due to weather conditions or natural disasters. Next came collisions on the railway or at level crossings with 9% each and fires on trains or alongside the line with 6%. Counted in hours, 49% of the interruptions were caused by derailment and 42% were due to weather conditions or natural disasters. Then come fires on trains or alongside the line with 6% and collisions on the railway or at level crossings with 2% each. Note that these only include accidents causing an interruption lasting a full day and that accidents at level crossings are the most common kind of accident on the railway but generally do not cause very long interruptions.

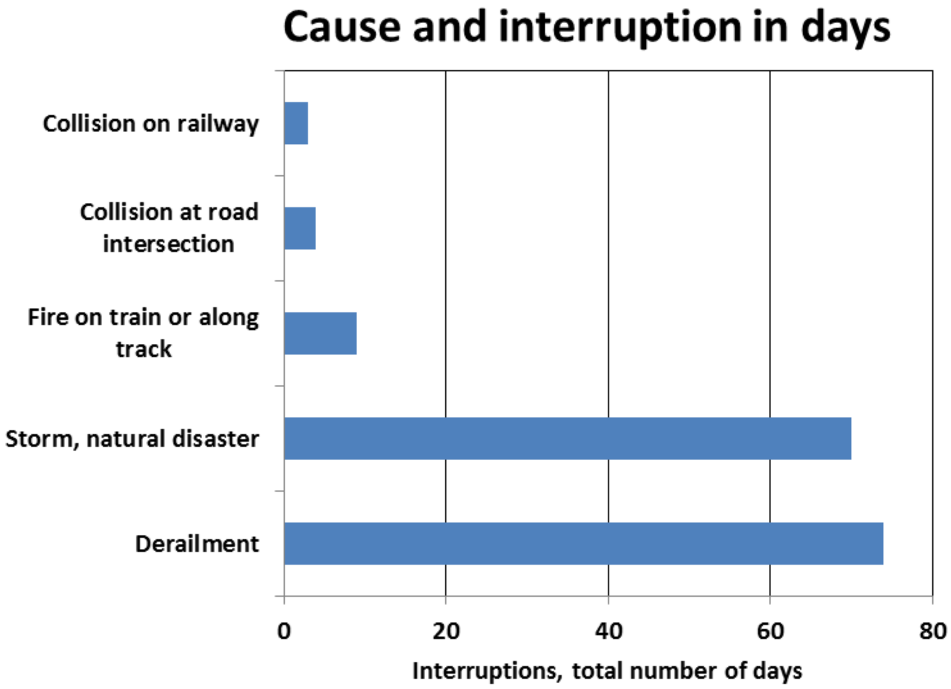

Figure 1: Causes of traffic interruptions.

Table 2: Number of traffic interruptions and hours of interruption by cause.

Cause	Number of cases	Share %	Number of days	Number of hours	Share %
Derailment	14	44%	74	1721	49%
Storm, natural disaster	10	31%	70	1468	42%
Fire on train or along track	2	6%	9	208	6%
Collision on railway	3	9%	4	70	2%
Collision at road intersection	3	9%	3	58	2%
	32	100%	160	3525	100%

Derailments and weather conditions thus appear to be the greatest problems when it comes to long interruptions in railway traffic. Figure 2 shows the distribution of derailments, interruptions caused by weather conditions and other interruptions over the period counted in days of interruption. It can be seen that derailments have occurred every year since 2005 with varying numbers of days of interruption. Storms caused relatively long interruptions during 5 of the 9 years since 2005. 39 days of interruption were caused by torrential rain, 21 by snowstorms and 9 were due to storms.

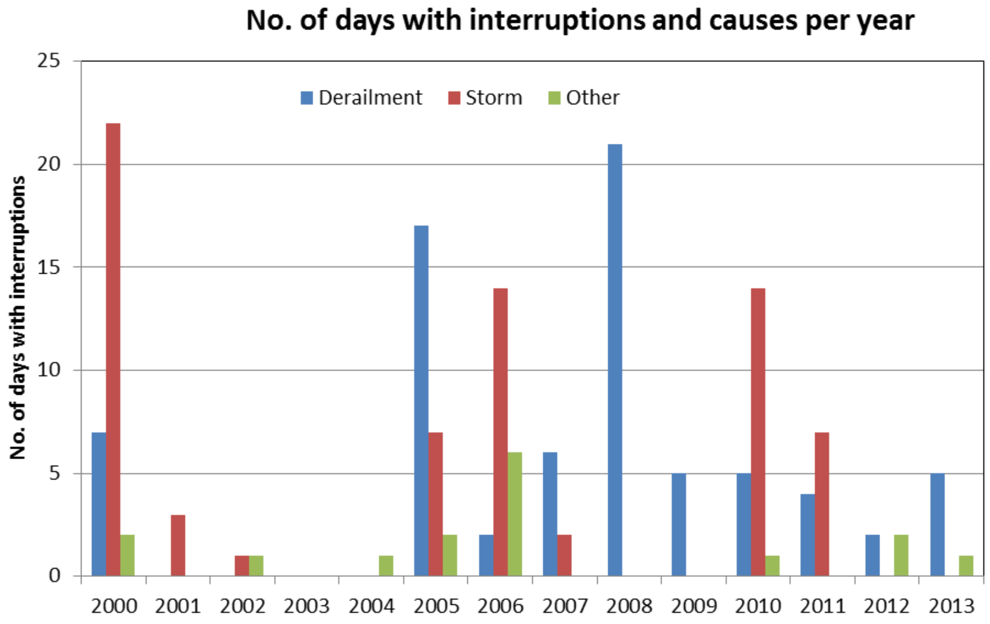

Figure 2: Most important causes of interruptions and distribution over time in number of days of interruption.

The question is what conclusions we can draw from this survey. It is evident that derailments and weather conditions cause the greatest problems as regards long interruptions of traffic. Our figures do not go further back but over the period in question the problems seem to have increased.

Derailments are problems that must be resolved within the railway system. It should to a certain degree be possible to predict such problems and take action to avoid them. The increase in the number of derailments might be due to both increased traffic and an accompanying increase in wear and maintenance backlog. This has also attracted great attention in Sweden among the railway's customers and players and among politicians, and measures to deal with the problem are an important feature in the Swedish Transport Administration's action plan.

The increase in extreme weather conditions is due to the climate crisis, which naturally does not only affect the railway. This is a problem that does not primarily have to do with the railway system but affects the whole of society to a greater or lesser extent. These problems are difficult to predict but it is possible to mitigate the consequences by taking action.

Other problems with collisions between trains and cars at level crossings, collisions between train movements and fires are things that can be worked on continuously in the railway's safety efforts with the aim of minimising the problems.

How can major traffic interruptions be avoided and their effects mitigated?

Table 3 shows possible measures to avoid major traffic interruptions. In summary, 72% had infrastructure-related causes and 25% operator-related causes. The question is how far it would have been possible to avoid these interruptions by means of maintenance, investments or some form of organisational measure.

Table 3: Possible measures to avoid traffic interruptions.

Alternative measures	Number of Interruptions	Share %
According to infrastructure		
Better maintenance of track	7	22%
Investment in signalling	1	3%
Collision at road intersection	3	9%
Better drainage	5	16%
Tree/rock securement	3	9%
Better snow preparedness	2	6%
Management of track work	2	6%
Total	23	72%
According to operators		
Better maintenance of track	4	13%
Management of train operation	4	13%
Total	8	25%
Other	1	3%
Total	32	100%

As regards derailments, better maintenance is obviously crucial but better inspections of the line to detect faults and deficiencies in time may also be important. It is thus a matter of dealing with the whole chain with preventive maintenance, inspection of the line's condition, and corrective maintenance before interruptions occur.

Roughly the same reasoning applies to derailments caused by vehicle deficiencies. With better detectors on the vehicles and on the tracks, faulty vehicles would be able to be detected in time in the same way as more preventive maintenance would reduce the risk of derailments caused by faulty vehicles. Investment in more track-friendly running gear would reduce wear to the track. Incentives for this may be needed, for example lower track access charges for vehicles with track-friendly running gear since these are often more expensive than vehicles with conventional running gear.

When it comes to interruptions caused by weather conditions it is obviously not possible to reduce the risk of adverse weather but on the other hand the risk of interruption can be reduced with preventive measures and measures to repair damage quickly. Regarding torrential rain, better drainage is one appropriate measure and anchoring trees to prevent storm damage another. At best the most serious deficiencies were rectified after the first extreme storms.

As regards storm damage, Hurricane Gudrun in 2005 brought down as much forest as in a normal year of felling in Sweden. But forests still exist and the meteorologists are warning of more extreme conditions in the future. We therefore need to be well prepared to handle new disturbances. This concerns snow preparedness to an even greater degree since snow cannot be cleared until it has fallen and here it is not only a matter of money but also of organisation. In this case, the deregulation of the railway has been of some importance since responsibility rests with several parties and the function was not given any high priority in procurement from the outset. The Swedish Transport Administration has now assumed overall responsibility for snow preparedness.

Other interruptions, for example interruptions due to collisions, are caused by incorrect operation, "the human factor", i.e. that personnel have not followed rules or instructions. This may in turn be a result of insufficient training, inspection and preparedness. Examples include collisions caused by incorrectly set braking, derailments in marshalling yards and collisions with work vehicles carrying out work on the line. In some cases, the risk of accidents is minimised with the help of technical systems.

Regarding collisions within the railway system these have been minimised through the introduction of ATC (Automatic Train Control), which brakes the train automatically if it is not running at the right speed or risks missing a stop signal. The system has however not been installed everywhere, in particular not in marshalling yards where it would be both costly and impractical to have such a system. One example of a major interruption that could have been avoided with ATC is the derailment at Borlänge marshalling yard in 2000 where a freight train was running too fast and left the line. It was also a high-risk derailment since a number of wagons carrying LPG had derailed and risked leaking their contents. Fortunately this did not happen, nor was anyone injured in the accident.

The root cause of the train running too fast, however, was that the driver was drunk. The question then is whether installing ATC in all marshalling yards, a multi-billion investment, is the best measure. An alternative is to install alcohol safety interlock devices in all locomotives, which would be cheaper than installing ATC in all marshalling yards but on the other hand would not prevent other kinds of accident. Yet another measure is better control and driver training, but this measure cannot eliminate all risks either.

Regarding collisions between cars and trains, a programme exists to reduce the risk of accidents through better protection for road users and grade-separated crossings. All new lines are constructed without level crossings so, technically speaking, it is possible to eliminate accidents by redesigning the crossings but this is not possible for practical and financial reasons.

When it comes to mitigating the consequences of interruptions, regardless of their cause, the possibility to divert traffic onto other lines is of strategic importance. Many interruptions have occurred on the Northern Main Line north of Vännäs where there is no parallel railway. South of Vännäs there is now the Bothnia Line which can fulfil this function.

Another measure to facilitate diversions is to ensure that good connections exist between different lines, e.g. in the form of triangle tracks between strategic links. A triangle track means that freight trains can run directly between two lines without the locomotive having to change ends. In order to facilitate diversions, the administrative routines for diverting trains can be simplified. The establishment of a National Traffic Management Centre, which is being planned by the Transport Administration, is also a measure that will facilitate control and diversion of train traffic.

How can major traffic interruptions be handled in socio-economic calculations?

The question is not only *whether* but also *how* measures to avoid major traffic interruptions can be handled in socio-economic calculations. Socio-economic calculations are usually mainly used to prioritise investments. Calculations of maintenance costs are not as fully developed. The calculations are generally of measures to improve the standard of the infrastructure or to reduce delays. Delays in this context are normal delays that generally concern the probability of a train arriving on time inside a certain interval, e.g. 5 minutes or the average delay. Calculations that take into account the risk of serious interruptions are generally not made.

On the hand, valuations are sometimes made afterwards of the negative impact of serious disturbances. E.g. in “Utredning Järnväg Vinter [Investigation Railway Winter]” (McKinsey, 2010) calculations were made of the total costs of delays and cancelled trains caused by the railway’s winter problems. These show costs in the billions for travellers’ time losses and a considerably smaller sum for freight traffic’s problems. The general problem with low freight values is also present here.

It has been identified above that some of the major interruptions could have been avoided with better inspection and maintenance of infrastructure and vehicles. The effects of major interruptions should be able to be identified. In the case of derailments, the cost of destroyed vehicles, freight and track is quantifiable and this is also done when insurance claims for the damage are settled. It should also be possible to quantify the costs for other trains that are affected, both the direct extra costs for delayed trains and the cost of diverting trains. Another example is delays in intermodal traffic, which lead to trucks and drivers being unoccupied while they wait for assignments and thereby income.

Another important aspect is the cost to customers of delays or destroyed freight caused by too long delays. In the long run, this may lead to customer losses through the company being unable to deliver on time or production costs soaring when production stops, which in turn may mean that customers choose other means of transportation than the railway to secure future deliveries.

Regarding traffic interruptions caused by weather conditions it is mainly measures that can reduce their consequences that are valued. It is then a matter of calculating the probability of a certain type of weather occurring and calculating the consequences in the form of additional costs for customers in the form of traffic interruptions in the same way as for maintenance. When it comes to drainage, culverts and similar can for example be dimensioned for the 100-year storm but due to the climate crisis this may now occur every 25 years or the culverts need to be dimensioned for even more severe rain. They then need to be upgraded to cope with even worse situations than previously. This might be relatively easy in the case of new construction or conversion but almost impossible to accomplish in the entire network at the same time.

The same applies to snow preparedness. It is hardly possible to cover for the railway functioning in all conceivable kinds of winter weather, and it is doubtful whether customers and/or the taxpayers are willing to pay for too far-reaching measures. There is probably greater understanding for the railway suffering problems under extreme weather conditions when all modes of transport are affected than for recurring everyday problems with minor disruptions. The measures needed are often organisational measures that it is difficult to make socio-economic calculations for.

Regarding capacity for alternative routes for diversions and triangle tracks, it should be possible to make a calculation that contributes to some degree to the calculations for these measures. This applies for example to investments already made in the Bothnia Line and the possible future investment in the Northern Bothnia Line.

When it comes to level crossings, a calculation method already exists for investments in measures to avoid accidents.

Comparison with methods proposed in this project

The methodology for socio-economic calculations proposed in this report is based on how the freight consignor’s cost function and transport costs vary with variations in transportation time. The data collection test included valuation of the additional costs that arise in the transport chain and for the recipient as a result of delays. In Appendix 3 about ”Operative costs due to delays of railway freight transports” the additional costs are calculated for a number of typical rail freight assignments at different levels of delay.

Chapter 0 contains a categorisation of the delays by extent and frequency into

- System killers (Large-Common)
- Catastrophic events (Large-Rare)
- Planned risks (Small-Common)
- Contingencies (Small-Rare)

The first two are not taken up in the data collection but are proposed to be dealt with in separate calculations. However, the additional costs caused in the transport chain in the data collection that are general are included and it should also be possible to use these costs for major traffic interruptions. Not included are for example the cost of rolling stock destroyed in derailments and the impact of the interruption on other trains, e.g. extra costs for diversions.

Vierth and Nyström’s (2013) study points out the lack of calculations for major traffic interruptions, among other things against the background of the analyses of the winter problems of 2009/2010 and 2010/2011. Freight traffic was very severely affected on these occasions and accounted for approximately 72-85% of the hours of delay but was valued at only 6-8% of the total socio-economic time losses.

One conclusion is that it may not be possible to develop a general methodology for all conceivable cases but it is important find basic methods to calculate freight time values and additional costs in the transport chain since they too constitute a portion of the costs when major traffic interruptions occur. Complementary calculations also need to be made of the most common types of traffic interruption that in this study have proven to be caused by derailments and storms.

Examples of additional costs to industry when extensive delays and traffic interruptions occur

Much of Swedish industry and perhaps the export industry in particular, rely on efficient transportation and properly operating infrastructure to get their products to their customers. Competition is often global and Sweden's geographical location far from the customers makes Swedish industry even more dependent on efficient and cost-effective transportation.

In parallel to this, there are also national environmental objectives and companies' own environmental objectives, which are largely identical, e.g. reduced use of fossil fuels. In this context, rail transportation is an excellent alternative. The railway as a mode of transportation, however, is not without its challenges: Capacity utilisation is high and maintenance is backlogged, which in combination increase the railway's vulnerability.

Below follows an analysis of the consequences of delays and traffic interruptions at a major Swedish company with extensive rail transportation.

Aim

The aim is to try to find more facts and quantify the impacts in the form of additional costs and lower revenues for industry. The details are taken from real events/disruptions and actual costs.

Method

Registered disruptions and interruptions in railway traffic together with booked costs and revenues constitute the basis for the work. Since it proved difficult to gather information in the form of disruption reports from the Swedish Transport Administration and train operators, known major events/disruptions have been complemented with assessments made by experts at the company. A single large company with extensive rail transportation has been used as a case study. The result is a balanced assessment of means and spread of disruptions, and their consequences.

Occurrence of different kinds of delay

Additional costs due to delays and traffic interruptions were investigated at three different levels:

- Delays and traffic interruptions of a number of hours' duration
- Interruptions and delays of one day's duration
- Interruptions and delays of several days' up to two weeks' duration

Delays of a number of hours' duration

Occur in 40% of the number of departures/arrivals; 24 departures/arrivals per week on average. Do not significantly affect costs or revenues. Absorbed by buffers/rearrangements and rescheduling.

Interruptions and delays of one day's duration

Generally caused by train cancellations. The interruptions are as a rule partial, i.e. sub-flows are affected, but can also in exceptional cases completely stop all deliveries and dispatches. Possible causes may be torn down overhead contact wires, locomotive problems, etc. Vary widely over time. Frequency of 1-8 trains per week. 2 trains per week on average over time.

Costs/revenues are affected up to 10% of the volume, i.e. 90% of the volume is handled by means of buffers, rescheduling, etc.

Interruptions of several days' up to 2 weeks' duration (as during winter 2009/2010)

Here again the interruptions may be partial or total in inbound and/or outbound traffic. Varies widely over time and is a function of capacity utilisation in the railway network, capacity utilisation at the company's plants and external disrupting factors, for example in the form of temperature, amount of snow, type of snow, autumn leaves, failures in the infrastructure and vehicle breakdowns.

Occur once a year on average (derailment at Grötingen in 2011, Malmö marshalling yard in 2010, Hallsberg marshalling yard in 2010, Gävle marshalling yard in 2010, cancelled ferries to the continent in 2010/2011, derailment in Denmark in 2012, etc) and on average last for 3 days. Spread 0-4 times per year, duration 1-14 days.

Interruptions longer than 1 day affect 75% of the volume.

Findings

Table 7 shows the calculated additional costs for delays and traffic interruptions. The calculation is based on the number of loaded trains per week and average load. On the basis of frequency of interruption, the proportion of the volume affected is calculated (tons in this case). Some of the delayed volume can be handled with existing stocks and by rescheduling. The remainder is the percentage of the delayed freight that has a direct impact on the company's finances though lost revenues. The total impact can be calculated by means of the freight value in SEK/ton. This is then converted into an additional cost.

This cost can then be put in relation to the transportation cost or the total freight value for the company's freight transportation by rail. The company says that the additional cost due to traffic interruption amounts to 18% of its rail freight transport costs. Shorter delays of a few hours do not give rise to any direct additional costs for the company but longer delays cause additional costs amounting to 4% of the rail freight costs. The really long delays account for 13% and thus constitute the major part of the additional cost,

In the above, the customer's additional costs have been calculated but the operator also has additional costs in the form of overtime, diversions and in the worst case hiring or rearranging locomotives and wagons. A method for calculating additional costs caused by delays has been developed based on a cost model for train production and is presented in Appendix 3. The costs have been calculated for different train products and delay durations.

The additional costs have been calculated as a mark-up on the cost of transportation in the different delay groups. These amount to approximately 10% of the total train cost and are thus not negligible and can turn economic profitability from profit into loss. The question is whether these costs are included in the operator's calculations from the beginning. From a socio-economic point of view this is of no importance since it is nonetheless an additional cost.

The company's additional costs thus amount to 18% and the operators' additional costs 10% of the total cost of freight transportation by rail or 28% all in all, which is a substantial additional cost.

Analysing the cost of the different kinds of delays, small delays of a couple of hours cause the highest costs to the operator since they are so frequent and no costs to the company (What does *no cost to the company* mean?). The average delays of one day cause roughly the same cost to the company as to the operator, i.e. 3-4% of the transport costs. The really severe interruptions of several days' duration cause the company extremely high costs but only minor costs to the operators according to these calculations.

It should be noted that these are costs due to major traffic interruptions that according to the above have become increasingly common. What have been calculated above are the costs to a company with extensive transportation by rail and to a larger or lesser degree dependent on rail transportation. In the long term, the company may suffer significant customer losses if deliveries become too unreliable and it may transfer much of its transportation to road or shipping and also relocate some of its production to other countries. It is very difficult to put a value on this but it would be very negative for Sweden's trade and industry and the Swedish economy.

Table 7: Summary of the occurrence of major delays and traffic interruptions and the cost to the company and the operators. Source: Information from a major Swedish company with extensive rail transportation.

Length of delays	Affected departures	Average	Frequency of dep.	Consequence	Share of train costs
Additional costs, customer					
Some hours	24 trains/week	3 trains/day 3 hours	40%	Minor, absorbed by buffers	0%
24 hours period	1-8 trains/week	2 trains/week 24 hours	3%	90% absorbed by buffers 10% affected	4%
1-2 weeks	0-4 times/year 1-14 days	Once/year 13 days	0,03%	25% absorbed by buffers 75% affected	13%
Total			43%		18%
Additional costs, operator				Additional costs, %	
1-5 hours	24 trains/week	3 hours	40%	15%	6%
24 hours	1-8 trains/week	24 hours	3%	76%	3%
One week	0-4 times/year	13 days	0,03%	76%	1%
Total			43%		10%
Total					28%

Discussion and conclusions

In this chapter we have made an analysis of major traffic interruptions in the railway's freight traffic between 2000 and 2013. These appear to have increased in particular after 2005, mainly for two reasons: derailments and extreme weather conditions. Derailments have increased as a consequence of increased traffic and thereby increased wear and backlogged maintenance, See Figures 6 and 7. The extreme weather conditions have increased due to the climate crisis.

As regards derailments, better maintenance is obviously crucial but better inspections of the line to detect faults and deficiencies in time may also be important. It is thus a matter of dealing with the whole chain with preventive maintenance, inspection of the line's condition, and corrective maintenance before interruptions occur. Roughly the same reasoning applies to derailments caused by vehicle faults. Investment in more track-friendly running gear would reduce wear to the track in the long term. Incentives for this may be needed, e.g. lower track access charges.

The effects of extreme weather conditions can be prevented with better drainage (torrential rain), by anchoring trees (storms) and by being better prepared for winter (snowstorms). The effects of both extreme weather and derailments can be mitigated by diverting traffic to other lines. It is important that there are parallel lines with sufficient capacity and direct connections between different lines, e.g. in the form of triangle tracks. It is also important that adequate routines exist for diverting trains and the National Traffic Management Centre being planned by the Transport Administration may come to be of real significance.

The consequences of major delays vary widely between different customers. While delays in passenger traffic are usually measured in minutes, demands regarding freight traffic vary from minutes up to several days. In a survey of freight customers' values (Lundberg 2006), 9% of the companies had additional costs for delays of less than one hour's duration while 45% had additional costs for delays of 4-6 hours and 40% for delays of a day or more.

Freight traffic's diurnal rhythm where products are often manufactured during the day and transported overnight is of great importance but sensitivity to disruptions varies with the type of product. Certain products such as perishable goods and newspapers become worthless if they do not arrive on time while for other products like iron ore and timber a few days' buffer stocks may exist. Sensitivity also varies with where in the value added chain transportation takes place and is generally greater the closer to the end customer the products come.

A more detailed analysis has also been made of the costs caused by delays to a major Swedish company with extensive rail transportation. At this company, delays of a couple of hours' duration could be managed with buffers and rescheduling. In the case of a day's delay, 10% of the volume was affected in the form of lost revenue and major delays of several days' duration affected the volume with substantial costs as a consequence together with a risk of losing customers later.

Information provided by the company also confirms the picture given by the survey of major traffic interruptions in Sweden. Major traffic interruptions of several days' duration have in recent years occurred at a rate of once a year on average. Delays of one day's duration occur for 3% of trains for this company and delays of a few hours for 40%.

Even if the company was able to cope with delays of a few hours' duration without any significant additional costs, the operator incurred substantial additional costs in respect of overtime etc. These costs have been roughly estimated by means of a cost model that was used in the project. That delays occur so frequently also means that locomotive and wagon needs must be dimensioned with substantial margins, which also increases costs. Less frequent delays also naturally increase the operator' costs and there are probably also no margins for this sand the inevitable result is thus lower profitability.

Both the industry and the operators thus lose money when delays and traffic interruptions occur. In relation to the transport costs, the company's losses amounted to 18% of the transport cost and the operators' additional costs to 10% of the transport costs. The additional costs thus amounted to 28% of the transport costs.

The total cost of transporting freight by rail can be roughly estimated to be approximately SEK 5 billion in 2012 (21 billion ton-kilometres x SEK 0,25/ton-km). If all transportation were to be affected as much as the company above, it would mean a total additional cost of 1.5 billion per year where the customers would account for 1 billion and the operators for 0.5 billion. This is, of course, not the case; some companies are more affected and others less affected; this is merely an example to illustrate the magnitude.

McKinsey (2010) estimated the additional socio-economic costs for freight traffic during winter 2009/2010 to amount to SEK 0.1 billion and SEK 0.2 billion in 2010/2011. Passenger traffic's additional socio-economic costs were at the same time estimated to be SEK 1.5 billion and 2.4 billion, respectively. According to these calculations, freight traffic would thus account for only a small proportion of the costs. The calculations concerned only the customer's additional costs for delays and cancelled trains where time costs are a significant factor. The fact that, in simple terms, one freight hour is valued at SEK 1/ton-hour and one passenger hour at approximately SEK 100/passenger-hour, which rather corresponds to SEK 1/kg-hour, naturally has a substantial impact on the calculations.

The methodology proposed in this report is based on how the freight consignor's cost function and transport costs vary with variations in transportation time. The data collection test included valuation of the additional costs that arise in the transport chain and for the recipient as a result of delays. This is general knowledge and is needed in all kinds of calculations.

The question is whether it is possible to develop general methods for all situations. Socio-economic calculations are usually used to prioritise investments and calculations for maintenance measures are seldom used. It is important that better calculations to value maintenance measures also be developed. Regarding the effects of extreme weather conditions, it is by no means certain that there is any point to developing general methods; they might possibly need to be made in each individual case. When it comes to winter preparedness this is for example very much a matter of organisational measures.

Another issue concerning methods is how a measure on a particular link in the railway network affects punctuality for the end customer. The calculations are often made at link level but the distance between the origin and destination of the freight may be very long and freight trains pass many links on their journey through Sweden and perhaps to other countries. A route approach is important in freight transportation and also a network approach when it comes to achieving a robust system where the freight can also take different routes when capacity problems and traffic interruptions occur.

Appendix 2: Data collection test – variables

In connection to the data collection test, the variables identified in chapter 3, describing transport attributed influenced by delays, have been sorted into three categories

1. Values to try to collect through surveys and interviews
2. Values to be estimated from other sources, e.g. ASEK, Samgods, other models
3. Values judged not possible to include currently; further development

Only variables connected to the range of costs defined in section 3.5 are listed in the table below. Variables that are sorted into category 1 above are in **bold**, variables in category 2 are <u>underlined</u> and variables belonging to category 3 are in *italics*.

Type of cost	Cost driver	Cost
Vehicle costs	Longer transport time (**vehicle-hours, type of vehicle**)	<u>SEK per hour per vehicle type</u>
	Longer transport distance (**vehicle-km**)	<u>SEK per km per vehicle type</u>
Staff costs	Extra working hours (**person-hours**, **type of industry/business**)	<u>SEK per hour per type of industry/business</u>
Extra transport costs	Using alternative vehicle (**type of vehicle, vehicle-hours**)	<u>SEK per hour per vehicle type</u>
	Extra transhipment on the road to alternative vehicle	Cost for transhipment on the road (**SEK**)
Delay costs for other planned shipments	*Schedule for vehicle, staff, …*	*Delay costs for other shipments*
Terminal costs	Extra storage at terminal	Cost for extra storage (**SEK**)
	Extra transhipment at the terminal	Cost for transhipment at terminal (**SEK**)
Goods receiver costs	**Effects of lacking goods**	Costs for lacking goods (**SEK**)
	Safety stock size (**hours**)	Cost of safety stock (<u>SEK per hour</u>)
System costs for general low reliability	*Number of back-up vehicles, staff, built-in extra time margins, …*	*Costs of back-up vehicles, staff, built-in extra time margins, …*

In order to use the collected data on costs in the model, further information on the transport relation is needed. Therefore, the following variables have to be included in the data collection as well:

Type of goods
Value of goods (**SEK/tonne**)
Size of shipment (**tonnes**)
Type of industry (receiving business)
Time margins at transhipment points/terminals
Characteristics of transport chain (**number of legs**, **transhipments**, **transport distance**, *rest of transport network*)
Special attention required to goods (**refrigerated/frozen goods**, **high-risk goods**)
Given a certain delay (hours) in different steps of the transport chain; the total delay at the receiver (**hours**)

Form

The tables above describe the data we need to estimate the costs of delays. The cost drivers and costs in the first table are dependent of

1) The magnitude of the delay
2) Where in the transport chain the delay occurs

Based on this, a form for collecting the data has been designed. The form was designed to be used in the small-scale test carried out in this project, and can be seen as a preliminary draft of the structure we intend to use for the data collection in a full-scale study.

A screen shot of the form can be found below. The form includes two tables. The first table is used to describe the transport relation studied. The second table is used to describe the effects of different delays, depending on 1) and 2) above.

The tables are designed to cover a transport chain with up to three legs and two transhipments (if used for shorter transport chains, the extra fields have to be ignored). The first table thus has seven sections of columns:

1) General information on the transport
    a. Transport buying company (Name, filled in as free text)
    b. Type of industry (Industry code SNI 2007: chosen from list of 88 entries, e.g. “17: Paper industry”)
    c. Transport chain (chosen from list, entries e.g. “truck-train-truck”)
    d. Shipment type (chosen from list: liquid bulk, dry bulk or general cargo)

    e. Goods requiring special attention (chosen from list: no, refrigerated goods, frozen goods, high-risk goods)

2) Description of leg 1 in the chain
    a. Vehicle type (chosen from list, e.g. “Heavy truck < 60 tonnes”)
    b. Transport distance (km)
    c. Commodity type (Samgods 34 commodity code: chosen from list, e.g. “1: Cereals”
    d. Unitised goods (yes/no)
    e. Shipment size (tonnes)
    f. Value (SEK)
3) Description of transhipment 1 in the chain
    a. Unloading time (hours)
    b. Time between unloading and loading (hours)
    c. Loading time (hours)
4) Description of leg 2 in the chain
    Identical to section 2)
5) Description of transhipment 2 in the chain
    Identical to section 3)
6) Description of leg 3 in the chain
    Identical to section 2)
7) Information about the receiver of the goods
    a. Size of safety stock (hours)

The second table has six sections of columns and five sections of rows. The six column sections describe effects/costs in leg 1-3, transhipment 1-2 and at the receiver, specified below. Each row section describes delays of different size, but occurring in the five different parts (leg 1/transhipment 1/leg 2/transhipment 2/leg 3) of the transport chain.

The column sections in this table are:

1) Effects in leg 1 in the chain
    a. Extra use of vehicle (vehicle hours)
    b. Extra working hours (person-hours and type of industry – chosen from list, but should normally be some kind of transporting business)
    c. Extra transport distance (vehicle-km)
    d. Use of alternative vehicle (type of vehicle – chosen from list – and vehicle hours)
    e. Cost for transhipment on the road (SEK)
2) Effects at transhipment 1 in the chain
    a. Extra working hours (person-hours and type of industry – chosen from list, but should normally be some kind of transport service business)
    b. Cost for extra storage (SEK)

    c. Cost for extra transhipment (SEK)
3) Effects in leg 2 in the chain
    Identical to section 1)
4) Effects at transhipment 2 in the chain
    Identical to section 2)
5) Effects in leg 3 in the chain
    Identical to section 1)
6) Effects at the receiver
    a. Total delay (hours)
    b. Effect of lacking goods (description, filled in as free text, and cost (SEK))
    c. Extra working hours (person-hours and type of industry – chosen from list)

Each row section describes delays occurring in different parts of the chain, starting in the column section corresponding to the leg/transhipment and then tracking the delay through the remaining parts of the chain until the receiver:

1) Delays occurring in leg 1
    a. Delay < 2 hours
    b. Delay 2-8 hours
    c. Delay 8-24 hours
    d. Delay 24-48 hours
    e. Delay > 48 hours
2) Delays occurring during transhipment 1
    a. As 1a.-1e.
3) Delays occurring in leg 2
    a. As 1a.-1e.
4) Delays occurring during transhipment 2
    a. As 1a.-1e.
5) Delays occurring in leg 3
    a. As 1a.-1e.

The lists of industry types, vehicle types and commodity types can be found below.

General information					Leg 1 in chain			
Transport buying company	Type of industry	Transport chain	Shipment type	GRSA	Vehicle type	Distance	Commodity type	Unitised goods
[free text]						[km]		

Effects of delays

	Leg 1 in chain							Transshipment 1	
	Extra use of vehicle	Extra working hours		Extra transport distance	Use of alternative vehicle		Transshipment on the road	Extra working hours	
Delay occuring in leg 1	Vehicle-hours	Person-hours	Type of industry	Vehicle-km	Type of vehicle	Vehicle-hours	Cost	Person-hours	Type of industry
< 2 hours	[vehicle-hours]	[person-hours]		[Vehicle-km]		[vehicle-hours]	[SEK]	[person-hours]	
2-8 hours	[vehicle-hours]	[person-hours]		[Vehicle-km]		[vehicle-hours]	[SEK]	[person-hours]	
8 -24 hours	[vehicle-hours]	[person-hours]		[Vehicle-km]		[vehicle-hours]	[SEK]	[person-hours]	
24-48 hours	[vehicle-hours]	[person-hours]		[Vehicle-km]		[vehicle-hours]	[SEK]	[person-hours]	
> 48 hours	[vehicle-hours]	[person-hours]		[Vehicle-km]		[vehicle-hours]	[SEK]	[person-hours]	
						Delay occuring during transshipment 1			
							< 2 hours	[person-hours]	
							2-8 hours	[person-hours]	
							8 -24 hours	[person-hours]	
							24-48 hours	[person-hours]	
							> 48 hours	[person-hours]	

		Transshipment 1			Leg 2 in chain	Transhipment 2	Leg 3 in chain	At the receiver
Shipment size	Value	Unloading time	Time btw un-/loading	Loading time	...	...	...	Size of safety stock
[tonnes]	[SEK]	[hours]	[hours]	[hours]	...	...	...	[hours]

		Leg 2 in chain	Transhipment 2	Leg 3 in chai	At the receiver				
Extra storage	Extra transshipment	...	...	...	Total delay	Effect of lacking goods		Extra working hours	
Cost	Cost	...	...	...	Hours	Description	Cost	Person-hours	Type of industry
[SEK]	[SEK]	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
[SEK]	[SEK]	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
[SEK]	[SEK]	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
[SEK]	[SEK]	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
[SEK]	[SEK]	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
[SEK]	[SEK]	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
[SEK]	[SEK]	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
[SEK]	[SEK]	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
[SEK]	[SEK]	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
[SEK]	[SEK]	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
Delay occuring in leg 2									
	< 2 hours	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
	2-8 hours	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
	8 -24 hours	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
	24-48 hours	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
	> 48 hours	...	...	...	[hours]	[free text]	[SEK]	[person-hours]	
	Delay occuring during transshipment 2								
		< 2 hours	...	...	[hours]	[free text]	[SEK]	[person-hours]	
		2-8 hours	...	...	[hours]	[free text]	[SEK]	[person-hours]	
		8 -24 hours	...	...	[hours]	[free text]	[SEK]	[person-hours]	
		24-48 hours	...	...	[hours]	[free text]	[SEK]	[person-hours]	
		> 48 hours	...	...	[hours]	[free text]	[SEK]	[person-hours]	
		Delay occuring in leg 3							
			< 2 hours	...	[hours]	[free text]	[SEK]	[person-hours]	
			2-8 hours	...	[hours]	[free text]	[SEK]	[person-hours]	
			8 -24 hours	...	[hours]	[free text]	[SEK]	[person-hours]	
			24-48 hours	...	[hours]	[free text]	[SEK]	[person-hours]	
			> 48 hours	...	[hours]	[free text]	[SEK]	[person-hours]	

Industry types (SNI 2007)	Vehicle types	Commodity types (Samgods 34)
01 Crop and animal production, hunting and related service activities 02 Forestry and logging 03 Fishing and aquaculture 05 Mining of coal and lignite 06 Extraction of crude petroleum and natural gas 07 Mining of metal ores 08 Other mining and quarrying 09 Mining support service activities 10 Manufacture of food products 11 Manufacture of beverages 12 Manufacture of tobacco products 13 Manufacture of textiles 14 Manufacture of wearing apparel 15 Manufacture of leather and related products 16 Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials 17 Manufacture of paper and paper products 18 Printing and reproduction of recorded media 19 Manufacture of coke and refined petroleum products 20 Manufacture of chemicals and chemical products 21 Manufacture of basic pharmaceutical products and pharmaceutical preparations 22 Manufacture of rubber and plastic products 23 Manufacture of other non-metallic mineral products 24 Manufacture of basic metals 25 Manufacture of fabricated metal products, except machinery and equipment 26 Manufacture of computer, electronic and optical products 27 Manufacture of electrical equipment 28 Manufacture of machinery and equipment n.e.c. 29 Manufacture of motor vehicles, trailers and semi-trailers 30 Manufacture of other transport equipment 31 Manufacture of furniture 32 Other manufacturing 33 Repair and installation of machinery and equipment 35 Electricity, gas, steam and air conditioning supply 36 Water collection, treatment and supply 37 Sewerage 38 Waste collection, treatment and disposal activities; materials recovery 39 Remediation activities and other waste management services 41 Construction of buildings 42 Civil engineering 43 Specialised construction activities 45 Wholesale and retail trade and repair of motor vehicles and motorcycles 46 Wholesale trade, except of motor vehicles and motorcycles 47 Retail trade, except of motor vehicles and motorcycles 49 Land transport and transport via pipelines 50 Water transport 51 Air transport 52 Warehousing and support activities for transportation 53 Postal and courier activities 55 Accommodation 56 Food and beverage service activities 58 Publishing activities 59 Motion picture, video and television programme production, sound recording and music publishing activities 60 Programming and broadcasting activities 61 Telecommunications 62 Computer programming, consultancy and related activities	-Car <3,5 tonnes -Lorry < 40 tonnes -Lorry < 60 tonnes -Combi train -Feeder train -Wagonload train -System train -Roro ships / container ships < 5 300 dwt / other ships < 20 000 dwt -Container ships > 5 300 dwt / other ships > 20 000 dwt -Road ferry -Rail ferry -Freight plane	1 Cereals 2 Potatoes, other vegetables, fresh or frozen, fresh fruit 3 Live animals 4 Sugar beet 5 Timber for paper industry (pulpwood) 6 Wood roughly squared or sawn lengthwise, sliced or peeled 7 Wood chips and wood waste 8 Other wood or cork 9 Textiles, textile articles and manmade fibres, other raw animal and vegetable materials 10 Foodstuff and animal fodder 11 Oil seeds and oleaginous fruits and fats 12 Solid mineral fuels 13 Crude petroleum 14 Petroleum products 15 Iron ore, iron and steel waste and blast-furnace dust 16 Non-ferrous ores and waste 17 Metal products 18 Cement, lime, manufactured building materials 19 Earth, sand and gravel 20 Other crude and manufactured minerals 21 Natural and chemical fertilizers 22 Coal chemicals 23 Chemicals other than coal chemicals and tar 24 Paper pulp and waste paper 25 Transport equipment, whether or not assembled, and parts thereof 26 Manufactures of metal

63 Information service activities 64 Financial service activities, except insurance and pension funding 65 Insurance, reinsurance and pension funding, except compulsory social security 66 Activities auxiliary to financial services and insurance activities 68 Real estate activities 69 Legal and accounting activities 70 Activities of head offices; management consultancy activities 71 Architectural and engineering activities; technical testing and analysis 72 Scientific research and development 73 Advertising and market research 74 Other professional, scientific and technical activities 75 Veterinary activities 77 Rental and leasing activities 78 Employment activities 79 Travel agency, tour operator and other reservation service and related activities 80 Security and investigation activities 81 Services to buildings and landscape activities 82 Office administrative, office support and other business support activities 84 Public administration and defence; compulsory social security 85 Education 86 Human health activities 87 Residential care activities 88 Social work activities without accommodation 90 Creative, arts and entertainment activities 91 Libraries, archives, museums and other cultural activities 92 Gambling and betting activities 93 Sports activities and amusement and recreation activities 94 Activities of membership organisations 95 Repair of computers and personal and household goods 96 Other personal service activities 97 Activities of households as employers of domestic personnel 98 Undifferentiated goods- and services-producing activities of private households for own use 99 Activities of extraterritorial organisations and bodies		27 Glass, glassware, ceramic products 28 Paper, paperboard; not manufactures 29 Leather textile, clothing, other manufactured articles than paper, paperboard and manufactures there 31 Timber for sawmill 32 Machinery, apparatus, engines, whether or not assembled, and parts thereof 33 Paper, paperboard and manufactures thereof 34 Wrapping material, used 35 Air freight

Appendix 3: Memo on operative costs due to delays of railway freight transports

1. Introduction and summary

The intention of this paper is to describe a possible general method to define the effects and costs of railway freight transport operation due to delays, e.g. due to accidents, infrastructure faults or infrastructure maintenance affecting the train operation.

The outlined method, although general, should be possible to apply to the socio-economic models used for freight transport studies.

Delays in a freight transport chain will of course have consequences on the delivery of the goods to customers, but it also affects transport costs. The delays may for example create a need for extra resources, such as vehicles and staff.

Consequences due to late delivery are not in the scope of this paper.

Today, railway freight transports normally have rather large resources (=transport capacity) in terms of the utilization of vehicles. This is due to many things such as:

- variations in transport demand,
- the need to aggregate the transport flows into large trains, which may have consequences for frequencies and stand-still waiting time,
- a need to run freight transports during night time.

Speaking in general terms, the situation may be different for different rail freight transport systems.

A general tendency of on-going attempts is of course to reduce costs by optimizing the utilisation of the resources, for example by keeping the rolling stock running 24 hours and 7 days per week. This is obviously hard to achieve, but affects the margins more or less built into the rail transport systems.

The following table gives a summary of the main results, i.e. the increase of total operational cost due to a delay (% rel to normal cost). The details on background estimates and calculations are given in section 4.

	Delay				
	1h	3h	6h	12h	24h
Wagon load					
Delay of the feeder transport to the marshalling/shunting yard	2%	7%	47%	89%	151%
Delay of the long distance railway transport	1%	6%	13%	37%	72%
Delay of the feeder transport from marshalling/shunting yard	1%	6%	18%	26%	26%
Train load					
Operated one cycle per 24 hrs	3%	8%	41%	85%	207%
Continuous (as many cycles as possible per 24 hrs)	3%	9%	44%	93%	226%
Inter modal block train					
Over night operation	7%	7%	25%	28%	48%

Up to 3h delay results in less than 10% additional costs. At 6h delay the cost will increase rapidly, and at 12h, in many cases with high utilization. the cost will be doubled. At 24h delay the cost will increase dramatic for trainload.

However, it should be understood that the purpose of this memo is not to provide final figures, but to describe a possible general method to define the cost increase of railway freight transport operation due to delays.

In the case of a disruption on a line due to e.g. an accident or fault of the infrastructure, all the trains, and transport chains using the trains, during the time of disruption will be subject to increased operative costs. In a socio-economic model it should be possible to roughly identify the transports, including the type of train used for the transport, influenced by a certain disruption in a railway node or link. This should make it possible to roughly calculate the total effect on operational cost due to such disruption.

2. Rail freight transportation systems

Rail freight transportation is traditionally split into a number of production systems with different characteristics. The main types are:

Wagon-load	Individual wagons, or groups of wagons, transported through a number of nodes where the various flows of wagons are aggregated and disaggregated depending on the origin-destination of each individual flow. Traditionally, the wagon-load system has a fairly large geographical coverage with terminals (partly industry sidings), shunting- and marshalling yards. Traditionally, the wagon load system is operated more or less over night with terminal pick-up in the afternoon and delivery the next morning, or pick-up day one and delivery day two. Over long distances two overnight transports may be required. Basically the transport follows the scheme: 1. Pick up of wagons in a terminal area 2. Transport to a major shunting or marshalling yard by a feeder train 3. Long distance haul to another major shunting or marshalling yard (4. Possibly one or more further long distance hauls) 5. Transport to a terminal by a feeder train 6. Delivery wagons in the terminal area Intermodal transports may utilise the wagon-load system fully or partly for the transport from one terminal to another.
Train-load	Large flows of goods, normally bulk such as ore or timber, are often transported by dedicated trains operated as shuttles between two terminals with loaded trains in one direction and empty trains in the other. Frequency may be one cycle per 24 hours or higher.
Intermodal block trains	Transportation of unit load devices (ULD) such as containers, swap-bodies and semitrailers are normally transported by block trains directly from one terminal to another. Some systems may have intermediate stops with unloading/loading of ULDs. In many relations the frequency is less than one cycle per 24 hours. It is seldom higher although this can be envisaged in the future. The block trains may have fixed train sets or train sizes adapted to the actual demand. Sometimes intermodal transports make use of the wagon-load system for the full or part of the rail transport.
High Speed freight trains	High speed freight trains generally transport mail and parcels overnight with late departures and early arrivals so that collection and sorting can be done at the terminals before departure and sorting and distribution upon arrival. They are competing with airplanes. Special wagons or modified passenger train equipment is often used. Today, this type of system is not very common. It has not been subject to evaluation.

Many of the systems have a 24 hour (overnight) frequency, but some are operated with a more or less continuous circulation of the trains.

Transport of various types of commodities and O-D relations may be fairly well attributed to these systems as regards the possible use of rail for the transportation.

3. Rail freight transportation costs

The costs of railway freight transports depend of course on many factors.

In national economic calculations transport costs are normally treated as costs/tonne for a set of different classes of commodities. The costs are normally split into fixed costs and costs related to distance and time. The time related costs consider such issues as driver and capital costs, although the latter must also be partly covered by the fixed costs due to stand still time.

Another issue is the fact that the transport cost must, or may, include the costs of empty return transportation or repositioning of the railway cars and/or unit load devices (ULDs). Whether or not this shall be the case, may depend on the probability that a new loaded transport for the car/ULD may be found close to the destination point of the first transport.

In the examples below, Transrail's tool TSDA (Transport System Design and Analysis) has been used to calculate the transportation costs for a few examples. The calculations by this tool are focusing on the business related costs of transport, but should not be understood as transportation prices as charged to customers. The TSDA model is based on calculated "Best Future Cost", i.e. costs at a sustainable level with regard to capital costs and assuming a best possible design of the operations considering such factors as need of resources and organisation. Cost level is in 2013 prices. The model has not been updated according to lately changed taxes and infrastructure charges, but this has minor importance to the qualitative approach of the proposed model.

4. Consequence of delays

The costs due to delays, or resources in order to cope with delays, depend on the type of transport system in general, and in specific on the design of each individual transport chain.

It is judged that the consequences of delays (1, 3, 6, 12 or 24 hours) to the rail transport may be estimated in a qualitative and general manner. Based on the transport cost items, this may be transferred to costs for the rail transport operation.

The following tables describe how the delays may be judged to influence the operative cost of the various types of railway transports.

The costs and increase of costs are calculated for some typical rail transport situations. The calculations of the transport costs are based on Transrail's tool TSDA

(Transport System Design and Analysis), see section 3. The results are given as percentages, which are considered to be fairly applicable also in other situations than the specific examples.

4.1. Wagon-load transport

As mentioned above the wagon load transport follows basically the scheme:

1. Pick up of wagons in a terminal area
2. Transport to a major shunting or marshalling yard by a feeder train
3. Long distance haul to another major shunting or marshalling yard
4. (Possibly one or more further long distance hauls)
5. Transport to a terminal by a feeder train
6. Delivery wagons in the terminal area

Delays due to disruption of one of the line hauls (one of the feeders or the long distance haul) give three situations:

2. Delay of the feeder transport to the marshalling/shunting yard
3. Delay of the long distance railway transport
5. Delay of the feeder transport from marshalling/shunting yard

Delays in one of these parts of the wagon load transport chain is judged to give the consequences, and impact on the cost of the transport, as described in the tables in the following sub-sections.

The example, and cost in column 2, refer to a transport using a Habins wagon and with the following data:

Long distance haul, electric traction, 700 km
Passing two marshalling and/or major shunting yards
Sum of feeder hauls (one direction), electric traction, 100 km
Sum of terminal hauls (one direction), diesel traction, 50 km

The cost calculation model includes reposition of the wagon after the first transport

Delay of the feeder transport to the marshalling/shunting yard

Item	Sum of costs (SEK)	Delay of the feeder transport to marshalling/shunting yard 1h	3h	6h	12h	24h	Judged consequence of delay, incl change of route	Increase of cost due to delay/change of route (% rel to normal cost) 1h	3h	6h	12h	24h
COST OF COMPLETE TRANSPORT	5388,2							**2%**	**7%**	**47%**	**89%**	**151%**
Wagon	1857,7							**0%**	**0%**	**0%**	**29%**	**29%**
Capital cost and insurance	1328,0	0	0	0	24	24	extra time for use of the w agon				38%	38%
Maintenance of wagon	337,9	0	0	0	100	100	km change of route				11%	11%
Charges	191,8											
Long distance train	1192,1							**4%**	**12%**	**60%**	**119%**	**238%**
Capital cost and insurance	366,7	0	0	0	0	0	hrs rental of loco					
Maintenance locomotive	138,3											
Energy	156,3											
Driver	498,5	1	3	6	12	24	hrs extra time + spare driver at delay 6h or more	9%	28%	142%	285%	570%
Charges	32,2											
Marshalling	207,8	0	10%	5%	5%	5%		**0%**	**10%**	**5%**	**5%**	**5%**
Feeder train	482,3							**13%**	**40%**	**373%**	**585%**	**989%**
Capital cost and insurance	99,2	0	0	24	24	24	hrs rental of loco			833%	833%	833%
Maintenance locomotive	36,9	0	0	0	100	100	km change of route				67%	67%
Energy	35,2	0	0	0	100	100	km change of route				67%	67%
Driver	302,4	1	3	6	12	24	hrs extra time + spare driver at delay 6h or more	21%	64%	322%	644%	1288%
Charges	8,6											
Terminal production	1623,1							**0%**	**0%**	**0%**	**0%**	**0%**
Capital cost and insurance	312,0											
Maintenance locomotive	71,2											
Energy	122,6											
Driver	1110,2											
Charges	7,2											
Terminal track	25,2							**0%**	**0%**	**0%**	**0%**	**0%**

Delay of the long distance railway transport

Item	Sum of costs (SEK)	Delay of the long distance railw ay transport 1h	3h	6h	12h	24h	Judged consequence of delay, incl change of route	Increase of cost due to delay/change of route (% rel to normal cost) 1h	3h	6h	12h	24h
COST OF COMPLETE TRANSPORT	5388,2							**1%**	**6%**	**13%**	**37%**	**72%**
Wagon	1857,7							**0%**	**0%**	**0%**	**29%**	**29%**
Capital cost and insurance	1328,0	0	0	0	24	24	extra time for use of the w agon				38%	38%
Maintenance of wagon	337,9	0	0	0	100	100	km change of route				11%	11%
Charges	191,8											
Long distance train	1192,1							**4%**	**12%**	**60%**	**123%**	**279%**
Capital cost and insurance	366,7	0	0	0	0	24	hrs rental of loco for departure next day					119%
Maintenance locomotive	138,3	0	0	0	100	100	km change of route				14%	14%
Energy	156,3	0	0	0	100	100	km change of route				14%	14%
Driver	498,5	1	3	6	12	24	hrs extra time + spare driver at delay 6h or more	9%	28%	142%	285%	570%
Charges	32,2											
Marshalling	207,8	0	10%	5%	5%	5%		**0%**	**10%**	**5%**	**5%**	**5%**
Feeder train	482,3							**0%**	**27%**	**0%**	**0%**	**0%**
Capital cost and insurance	99,2											
Maintenance locomotive	36,9											
Energy	35,2											
Driver	302,4	0	2	0	0	0	delayed departure due to late arrival		43%			
Charges	8,6											
Terminal production	1623,1							**0%**	**3%**	**0%**	**0%**	**0%**
Capital cost and insurance	312,0											
Maintenance locomotive	71,2											
Energy	122,6											
Driver	1110,2	0	1	0	0	0	delayed departure due to late arrival		5%			
Charges	7,2											
Terminal track	25,2							**0%**	**0%**	**0%**	**0%**	**0%**

Delay of the feeder transport from marshalling/shunting yard

Item	Sum of costs (SEK)	Delay of the feeder transport from marshalling/shunting yard					Judged consequence of delay, incl change of route	Increase of cost due to delay/change of route (% rel to normal cost)				
		1h	3h	6h	12h	24h		1h	3h	6h	12h	24h
COST OF COMPLETE TRANSPORT	5388,2							**1%**	**6%**	**18%**	**26%**	**26%**
Wagon	1857,7							**0%**	**0%**	**0%**	**29%**	**29%**
Capital cost and insurance	1328,0	0	0	0	24	24	extra time for use of the wagon				38%	38%
Maintenance of wagon	337,9	0	0	0	100	100	km change of route				11%	11%
Charges	191,8											
Long distance train	1192,1											
Capital cost and insurance	366,7											
Maintenance locomotive	138,3											
Energy	156,3											
Driver	498,5											
Charges	32,2											
Marshalling	207,8							**0%**	**0%**	**0%**	**0%**	**0%**
Feeder train	482,3							**13%**	**40%**	**202%**	**181%**	**181%**
Capital cost and insurance	99,2	0	0	0	24	24	hrs rental of loco for departure next day				833%	833%
Maintenance locomotive	36,9	0	0	0	100	100	km change of route				67%	67%
Energy	35,2	0	0	0	100	100	km change of route				67%	67%
Driver	302,4	1	3	6	0	0	hrs extra time + spare driver at delay 6h or more	21%	64%	322%		
Charges	8,6											
Terminal production	1623,1							**0%**	**7%**	**0%**	**0%**	**0%**
Capital cost and insurance	312,0											
Maintenance locomotive	71,2											
Energy	122,6											
Driver	1110,2	0	2	0	0	0	delayed departure due to late arrival		10%			
Charges	7,2											
Terminal track	25,2							**0%**	**0%**	**0%**	**0%**	**0%**

4.2. Train load

The example, and costs in column 2, refer to a transport with the following data:

Loaded train weight	1100 ton
Distance (one direction)	300 km
Electric traction	
Time at both terminals	5 hours

The cost calculation model includes return with the train empty.

The sub sections describe two cases:

- The train operated one cycle per 24 hours
- Continuous (as many cycles as possible per 24 hours, but respecting the terminal times)

One cycle per 24 hours

Item	Sum of costs (SEK)	Delay of the railway transport					Judged consequence of delay, incl change of route	Increase of cost due to delay/change of route (% rel to normal cost)				
		1h	3h	6h	12h	24h		1h	3h	6h	12h	24h
COST OF COMPLETE TRA	**35,4**							**3%**	**8%**	**41%**	**85%**	**207%**
Set of wagons	5,5							**0%**	**0%**	**0%**	**0%**	**0%**
Capital cost wagons	2,8	0	0	0	0	24	hrs rental of train set					**0%**
Maintenance wagons	2,6	0	0	0	100	100	km change of route				**0%**	**0%**
Railway transport	**28,3**							**3%**	**10%**	**51%**	**106%**	**258%**
Capital cost locomotive	12,0	0	0	0	0	24	hrs rental of loco					**122%**
Maintenance locomotive	2,6	0	0	0	100	100	km change of route				**33%**	**33%**
Energy	2,2	0	0	0	100	100	km change of route				**17%**	**17%**
Infrastructure charges	2,4											
Driver	9,2	1	3	6	12	24	hrs additional time + spare driver at 6h or more	**10%**	**31%**	**157%**	**313%**	**627%**
Terminal	**1,6**	0	0	5%	10%	5%	increased capacity (assume normal terminal time 4+1 hr)			**0%**	**0%**	**0%**

Continuous (as many cycles as possible per 24 hrs)

Item	Sum of costs (SEK)	Delay of the railway transport 1h	3h	6h	12h	24h	Judged consequence of delay, incl change of route	Increase of cost due to delay/change of route (% rel to normal cost) 1h	3h	6h	12h	24h
COST OF COMPLETE TRA	**32,3**							**3%**	**9%**	**44%**	**93%**	**226%**
Set of wagons	4,9							**0%**	**0%**	**0%**	**0%**	**0%**
Capital cost wagons	2,3	0	0	0	0	24	hrs rental of train set					**0%**
Maintenance wagons	2,6	0	0	0	100	100	km change of route				**0%**	**0%**
Railway transport	**26,1**							**4%**	**11%**	**55%**	**114%**	**280%**
Capital cost locomotive	9,8	0	0	0	0	24	hrs rental of loco					**149%**
Maintenance locomotive	2,6	0	0	0	100	100	km change of route				**33%**	**33%**
Energy	2,2	0	0	0	100	100	km change of route				**17%**	**17%**
Infrastructure charges	2,4											
Driver	9,2	1	3	6	12	24	hrs additional time + spare driver at 6h or more	**10%**	**31%**	**157%**	**313%**	**627%**
Terminal	**1,3**	0	0	5%	10%	5%	increased capacity (assume normal terminal time 4+1 hr)			**0%**	**0%**	**0%**

4.3. Intermodal block train

The example, and cost in column 2, refer to a transport using a 7,45 m swap-body and with the following data:

Load	11 tonne (80% of max)
Long distance haul, electric traction	600 km
Rail haul concept	overnight
Passing of two intermodal terminals	
Sum of road hauls (one direction)	50 km

The cost calculation model includes repositioning of the swap-body after the first transport.

Item	Sum of costs (SEK)	Delay of the railway transport					Judged consequence of delay, incl change of route	Increase of cost due to delay/change of route (% rel to normal cost)				
		1h	3h	6h	12h	24h		1h	3h	6h	12h	24h
COST OF COMPLETE TRANSPORT	**2897**							**7%**	**7%**	**25%**	**28%**	**48%**
Unit Load Device (ULD)	**291**							0%	0%	0%	0%	0%
Capital cost	159											
Maintenance	132											
Interregional transport	**566**							**0%**	**1%**	**5%**	**15%**	**121%**
Capial cost locomotive	97	0	0	0	0	24	hrs rental of loco					389%
Maintenance locomotive	79	0	0	0	100	100	km change of route				17%	17%
Capital cost w agon	43	0	0	0	0	24	hrs rental of trainset					389%
Maintenace w agon	59	0	0	0	100	100	km change of route				1%	1%
Energy/fuel	63	0	0	0	100	100	km change of route				17%	17%
Infastructure charges	55											
Driver	170	1	3	6	12	24	hrs extra time + spare driver at delay 6h or more	1%	3%	17%	35%	69%
Terminal	**552**	0	0	5%	10%	5%	additional capacite (assumed normal time 4+1 h)			**5%**	**10%**	**5%**
Regional road transport	**1489**							**14%**	**14%**	**46%**	**46%**	**46%**
Capital cost road vehicle	261	0	0	4	4	4	hrs spare			182%	182%	182%
Maintenance road vehicle	72											
Fuel	259											
Taxes and insurance	213											
Driver	684	1	1	1	1	1	additional time due to change of driving plan	30%	30%	30%	30%	30%

5. Consequences of a disruption on a railway line

In the case of a disruption on a line due to e.g. an accident or fault of the infrastructure, all the trains, and transport chains using the trains, during the time of disruption will be subject to increased operative costs. There may also be knock-on effects, e.g. that the departure of a feeder train including wagons from many long haul trains is delayed due to late arrival of one of the long haul trains.

In a socio-economic model the transport flows from origin to destination of different commodities are calculated, including allocation to different modes of transport and distribution on links and nodes.

The type of railway transportation, according to section 2, may be roughly defined from the type of commodity, size of the annual flow and/or normal transport cost.

The delays to transports and operative costs due to a disruption may be calculated applying the estimations according to the tables in Section 4.

Presently the suggested calculations of delays may be used to a posteriori evaluation of the costs for delayed freight transports by rail. This could for example be applied to situations with major disturbances, such as the blocking of Hallsberg marshalling yard by heavy snowfall and lack of snow removal, but also for more "normal" delays such as the situations outlined in Section 4. By doing this for all delays during a longer period, the delay costs and their development over time may be estimated. It may provide a more correct estimate than the one we obtain by using for example the delay costs according to ASEK 5 (which are the value of time for the goods multiplied with the delay times and a factor two (2)).

In situations with capacity constraints in the railway system, it may for example be possible to relate the delay/disturbance distributions to the utilization rates of the tracks, the amount of single tracks versus double tracks, etc. through a statistical analysis. Given such information and data it might be possible to start evaluation of delays/disturbances in socio-economic evaluations and comparisons of scenarios. Various methods exist for handling railway flow capacities in the national freight model, Samgods, and we are working with methods for estimating the capacity in terms of number of passenger and freight trains as a consequence of the time tables and actual infrastructure available in different rail transport corridors.