Mätningar möjliggör framtidens järnväg för alla

Vetenskaplig Rapport

Metodik för att mäta tillgänglighet

Ragne Emardson och Leslie Pendrill

SP Sveriges Tekniska Forskningsinstitut, enheten för Mätteknik

Catherine Sundling, Birgitta Berglund och Mats Nilsson

Stockholms Universitet, Psykologiska Institutionen

INNEHÅLLSFÖRTECKNING

Bakgrund

Denna rapport är resultatet av forskningsprojektet MÄTNINGAR MÖJLIGGÖR FRAMTIDENS JÄRNVÄG FÖR ALLA som genomförts i samarbete mellan SP Sveriges Tekniska Forskningsinstitut, enheten för Mätteknik och Stockholms Universitet, Psykologiska institutionen. Projektet finansierades av Trafikverket.

Inledning

Trafikverkets vision är att järnvägssystemet skall vara tillgängligt för resenärer med funktionsnedsättning. Exempel på svårigheter personer med funktionsnedsättning kan stöta på i samband med tågresor är tillgänglighet till information om tidtabeller och anslutningsmöjligheter, hjälpmedel vid stationer och terminaler samt möjlighet till hjälp att förflytta sig från station in i tåget. Till detta sällar sig servicefunktioner på tåg; dvs manövreringsbarhet, märkning, PC-uttag etc. (t ex för blinda). Problematiken är aktuell under alla delar av resan; från idén att göra resan vid utgångspunkten till att ha kommit slutgiltigt fram till nya platsen för den tänkta verksamheten. Olika åtgärder kan sättas in för att förbättra och öka tillgängligheten för resenärer med funktionsnedsättning. Vilka åtgärder som har störst positiv inverkan samt är mest kostnadseffektiva är dock inte självklart. Även om olika typer av mätningar görs för att leta upp problemområden återstår frågan hur mätningarna skall hanteras för att man skall kunna dra korrekta slutsatser? En av de största utmaningarna i ergonomin för personer med funktionsnedsättning ligger just att kunna mäta och bedöma, särskilt där människan står i fokus.

Vi har drivit ett projekt med syfte att utveckla en metodik för att mäta i vilken utsträckning resenärer med funktionsnedsättning kan använda järnväg som en del i hela resan. De mätmetoder – särskilt där människan är en nyckelkomponent i mätsystemet - som tagits fram kommer att kunna ligga till grund för en objektiv utvärdering av tillgänglighet. Mätningarna kommer också att kunna användas för att rikta förbättringarna mot de områden där de har störst positiv inverkan. Med hjälp av de metoder som utvecklats inom projektet kommer de mätningar som görs kunna användas för beslutsfattande om vilka åtgärder som bör göras för att göra spårtransportsystemet mer tillgängligt för personer med funktionsnedsättning.

Projektet innebär att utveckla en mätmetodik. Mätinstrumentet där människan står i fokus består av frågeformulär, intervjuer samt observationsprotokoll. Alla mätningar som ingår i projektet baseras på kvalitetssäkrad mätteknik vilket är en förutsättning för att utförda mätningar skall kunna ligga till grund för beslutsfattande och för hantering av olika typer av risker.

Projektet har resulterat i framförallt en ny metodik där människan är en nyckelkomponent i mätsystemet i den omgivning som är spårtransportsystemet. Metodiken består av mätmetoder, formulär samt analysmetoder. Resultatet av mätningar baserat på metodiken kommer att kunna användas för att rikta förbättringarna mot de områden där de har störst positiv inverkan. Detta kommer att leda till en större tillgänglighet till samt större användbarhet av järnvägen för resenärer med funktionsnedsättning.

I denna rapport sammanfattar vi arbetet runt utvecklingen av metodiken. Vi börjar med de frågeställningar som måste ställas innan denna typ av arbete kan påbörjas. Vi går sedan igenom processen för mätningar av nya storheter. Detta är en relativt generisk beskrivning vilket sedan blir mer konkret mot just tillgänglighet när vi beskriver det tillvägagångsätt vi använt. En mer detaljerad beskrivning av de olika stegen i vårt tillvägagångssätt finns sedan i de appendix som ligger sist i denna rapport.

FRÅGESTÄLLNINGAR

En lista på de huvudsakliga frågeställningarna vi har kan vara:

- Kan vi mäta tillgänglighet?
- Kan vi lita på resultaten?
- Hur vet vi om den förbättras?
- Vad bör vi göra för att förbättra tillgängligheten?

KAN VI MÄTA TILLGÄNGLIGHET?

Den första från vi måste ställa oss är om vi kan mäta tillgänglighet och vad är i så fall syftet med dessa mätningar. Först efter att vi beslutat syftet med våra mätningar kan vi bestämma vad som ingår i begreppet tillgänglighet.

KAN VI LITA PÅ RESULTATEN?

Vad gäller alla typer av mätningar är det centralt att vi kan lita på de mätresultat vi har. Detta innebär inte nödvändigtvis att vi har mätningar med mycket hög noggrannhet utan att vi har tillräckligt hög noggrannhet för de tillämpningar där mätningarna skall användas. För att resultaten skall vara pålitliga krävs att de faktiskt mäter det vi är intresserade av. Detta kallas ofta för att säkerställa validiteten i mätningarna, se nästa kapitel. Vi behöver också ha en uppskattning av osäkerheten i mätningarna. Detta ger oss information om hur mycket vi kan lita på resultaten, vilka slutsatser vi kan dra samt om vi behöver göra fler mätningar för att minska osäkerheten.

HUR VET VI OM DEN FÖRBÄTTRAS?

För att kunna avgöra om tillgängligheten påverkas av de olika insatser som genomförs behöver vi kunna jämföra mätningar över tiden. Vi vill kunna få svar på om tillgängligheten 2016 är bättre och i så fall hur mycket bättre än tillgängligheten 2015. För att kunna jämföra mätningar både över tid och med varandra för olika situationer behövs någon typ av referens. Mer diskussion om referenser finns i nästa kapitel.

VAD BÖR VI GÖRA FÖR ATT FÖRBÄTTRA TILLGÄNGLIGHETEN?

Genom att bryta ner vår komplexa parameter tillgänglighet i sina beståndsdelar har vi möjligheten att se vad som påverkar utfallet mest. Denna typ av studie kan sedan genomföras som en känslighetsanalys.

Process för mätningar av nya storheter

För att utveckla en metodik för mätning av nya storheter behöver vi genomföra ett antal aktiviteter. En lista på moment som bör genomföras finns nedan:

- Definiera begreppet
- Bestämma kontext
- Identifiera mätinstrument och tekniker
- Säkerställa validiteten
- Identifiera skalor
- Definiera en referens för att göra mätningar spårbara

Definiera begreppet

Det första vi måste göra när vi skall utveckla en metodik för att mäta en ny storhet är att definiera begreppet. I detta fall måste vi definiera vad vi menar med tillgänglighet.

Bestämma kontext

Vi behöver också bestämma i vilket kontext vi använder begreppet. I detta fall kommer det vara tillgänglighet till tågtrafik för personer med någon typ av funktionsnedsättning.

Identifiera mätinstrument och tekniker

För att kunna mäta tillgänglighet måste vi identifiera vilka typ av mätinstrument eller tekniker som behövs. Vi har utvecklat mätinstrument i form av frågeformulär, intervjuer samt observationsprotokoll.

Säkerställa validiteten

Det spelar ingen roll hur bra en mätning är om den inte mäter och ger information om det vi söker. Detta brukar kallas mätningens validitet. För att våra mätningar skall vara användbara behöver vi alltså säkerställa validiteten hos mätningarna.

Identifiera skalor

Enkäter används ofta för att mäta kvalitativa variabler såsom känslor och attityder på olika skattningsskalor. Statistiska metoder för mätningar på skattningsskalor måste ta hänsyn till dessas ranginvarianta egenskaper *Svensson* [2000]. Det innebär att metoderna ska vara opåverkad av en ommärkning av skalkategorierna.

Stevens [1946] delade upp mätskalorna i fem olika kategorier. Dessa är

- Nominal
- Ordinal
- Interval
- Ratio

Nominella skala eller ibland även kallad kategoriskala skiljer på föremål eller ämnen baserat på deras klassificeringar eller kategorier de tillhör. Några exempel är kön, nationalitet, språkgrupp, och biologiska arter.

Den ordinala skalan möjliggör rangordning genom vilken mätningar kan sorteras. Det finns däremot ingen information om graden av skillnad mellan mätningarna. Denna typ är mycket vanlig när det gäller mätningar med människan som instrument. Exempel på storheter som använder eller skulle kunna använda denna typ av skala är elegans, skönhet, naturlighet osv.

Mätningar på en intervallskala har en väl definierad skillnad mellan sig. Dock finns ingen information om det relativa förhållandet mellan dem. Ett typiskt exempel är temperaturmätningar på Celsius-skala, som har en godtyckligt definierad nollpunkt (fryspunkten för ett visst ämne under särskilda förhållanden). Vi kan enkelt säga att skillnaden mellan noll och fem grader är lika stor som skillnaden mellan fem och tio. Det finns dock ingen betydelse i uttryck som ”vad är dubbelt som varmt som noll grader?” eftersom multiplikation och division inte är operatorer som fungerar på en intervallskala.

De flesta mätningar i naturvetenskap och teknik sker på ratio-skalor. Exempel på storheter som normalt mäts på en ratio-skala är massa, längd och tidsintervall. Gemensamt för dessa är att de har en väl definierad nollpunkt. Detta innebär att vi kan använda ”vanliga” operatorer som multiplikation och division. Noterbart är att temperaturmätningar på Kelvin-skalan är på en ratio-skala tillskillnad från Celsius-skalan som är en intervall-skala.

I detta projekt har vi använt oss av en modell som bygger på en tillgänglighetsfunktion som opererar på mängden barriärer som en resande kan träffa på längs en resa [*Emardson et al.*, 2012]. Denna funktion returnerar ett värde mellan noll och ett baserat på hur svår barriären anses vara. Utdata från funktionen är definierad på en ratio-skala vilket gör att efterföljande mätningar också är på en ratio-skala.

Definiera en referens för att göra mätningar spårbara

För att mätningarna skall vara jämförbara både över tid och mellan olika system måste vi ha någon typ av referenser. Vi ville ju ha svar på frågor om tillgängligheten 2016 är bättre och i så fall hur mycket bättre än tillgängligheten 2015. För att kunna göra detta måste vi veta att en mätning av tillgängligheten ett år kan jämföras med en ny mätning ett annat år. När vi handskas med fysiska mätningar uppnås detta genom att relatera relevanta mätningar till nationella eller internationella normaler genom en obruten kedja av jämförelser [*Cox och Harris*, 2006]. För mätningar av icke-fysikaliska parametrar vill vi ha ett liknande system. Det finns dock inga internationella standarder som liknar det internationella SI-systemet. Därför måste vi hitta alternativa sätt att inrätta system som gör att jämförelser över tid och mellan länder är möjliga. Man kan tänka sig olika angreppssätt. *Berglund et al*. [1992] använde tex ljud som referens vid mätning av känslighet för lukter hos rökare och icke-rökare. Ett annat sätt är att använda specifika referenser som vi säkert vet inte har ändrats sedan den föregående mätningen. Dessa kan baseras på olika modeller som byggs upp och som inte ändras över tiden.

TILLVÄGAGÅNGSSÄTTET

Vårt arbete har deltats upp i ett antal arbetspaket som tillsammans skall matcha processen för att mäta nya storheter och därigenom kunna ge svar på de olika frågor vi tog upp i kapitel I.

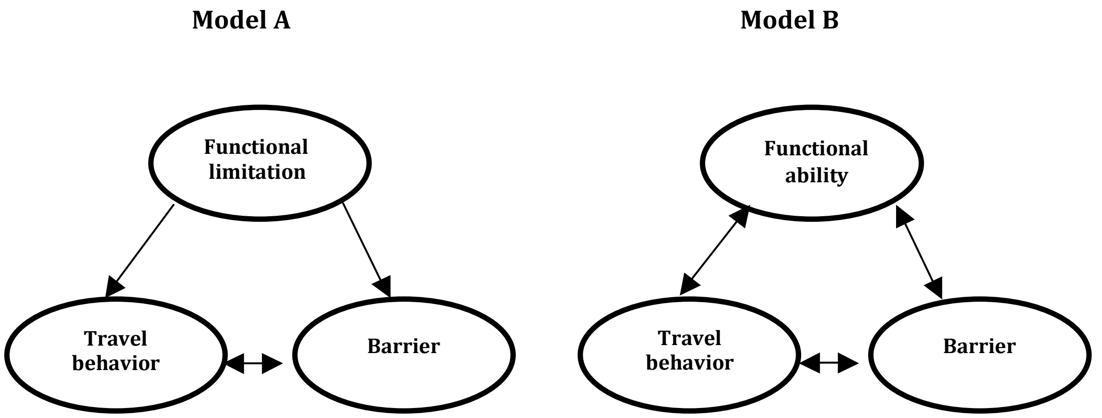
- Urvalsstudie
- Gruppering av barriärer
- Mätning av barriärer
- Modellering av tillgänglighet
- Koppling mellan mätning och beslutsfattande

URVALSSTUDIE

Den första studien syftar till att konstruera referensgrupper (äldre samt handikappidrottare), vilka ska ligga till grund för de senare studierna. Huvudsyftet är att finna personer samt kunna gruppera dessa. Centralt i vår studie är att finna en grupp personer som väl representerar en större grupp av resenärer. Urvalsprocessen är av stor betydelse för giltigheten av mätningarna; dess validitet.

För att finna denna grupp och utveckla en metodik för att mäta i vilken i vilken utsträckning resenärer med funktionsnedsättningar kan använda järnväg som en del i hela resan, genomförde vi en enkätstudie med 1 000 slumpmässigt utvalda äldre personer (65-85 år) i Stockholms län. Svarsfrekvensen var 57%. Anledningen till att vi valde äldre personer var, förutom att de är en växande grupp i samhället, att de har olika typer av funktionsnedsättningar och ofta flera samtidiga funktionsnedsättningar.

Vi fann att respondenternas upplevda tillgänglighet påverkas av deras typ av funktionsnedsättning, grad av funktionsförmåga och deras resebeteende i interaktion med de barriärer de möter under en resa (Figur 1).



FIGUR 1 **UPPLEVD TILLGÄNGLIGHET TILL HELA RESAN MODELLERAD FÖR RESENÄRER MED OLIKA TYPER AV FUNKTIONSNEDSÄTTNINGAR (MODELL A) ELLER FÖR RESENÄRER MED OLIKA GRAD AV FUNKTIONSNEDSÄTTNING (MODEL B).**

Tillgängligheten vid tågresor befanns vara god; endast 10% var mycket missnöjda. Resemiljön upplevdes som minst tillgänglig av dem som hade rörelsehinder eller långvarig smärta samt de som hade mer än en funktionsnedsättning/sjukdom eller mycket låg funktionsförmåga. De viktigaste upplevda barriärerna var, för respondenter med hög funktionsförmåga, resekostnader och punktlighet. För respondenter med låg funktionsförmåga upplevdes den egna hälsan som den viktigaste barriären.

Inom denna forskningsstudie utvecklade vi ett generellt urvalsinstrument för speciella grupper av individer (i detta fall personer med olika slags funktionsnedsättning). Genom att bygga in detta urvalsinstrument i det mer omfattande frågeformuläret, blev det möjligt att välja ut definierade personer med olika slags funktionsnedsättning, utifrån deras svarsprofil för vissa förutbestämda målfrågor. På detta sätt var det möjligt att välja ut deltagare i en efterföljande intervjustudie där syftet var att kalibrera mätningen av tillgänglighet för grupper med olika funktionsnedsättningar. Genom ett definierat urval för var och en av de olika slagen av funktionsnedsättningar blir det möjligt att bestämma den andel potentiella resenärer som skulle kunna rekryteras som nya resenärer.

Gruppering av barriärer

Detta steg syftar till att samla in upplevda barriärer vid tågresor och undersöka deras kortsiktiga och långsiktiga konsekvenser för resenären samt att ta fram underlag för att välja ut barriärer för viktning. Vi använder en metod som kallas ”Critical incidents”. Denna metod är explorativ och kan därför användas som grund för teoribyggande. En kritisk incident är en händelse som är särskilt tillfredsställande eller otillfredsställande. Genom att använda denna metod kan man identifiera de viktigaste upplevda barriärerna och fånga ett brett spektrum av upplevelser utan att styra deltagarna i någon viss riktning. Det möjliggör därför en objektiv utvärdering av upplevelsen av barriärer som resenärerna stött på. Den ger också insyn i deltagarens beslutsprocess.

Vi har i detta steg genomfört intervjuer med 30 äldre personer med olika typer av funktionsnedsättning/sjukdom samt olika grad av funktionsförmåga. De har fritt fått berätta om händelser de tyckt påverkat upplevelsen av en resa, där tåg varit åtminstone en del av resan. Däremot har inte incidenten nödvändigtvis behövt inträffa just vid den del som berört tåget, utan exempelvis vid en anslutande bussresa. Dessa incidenter, har sedan kategoriserats av två, av varandra oberoende personer, till två dimensioner; en *platsdimension* som hänför sig till resemiljön och en *tidsdimension* som har att göra med när under resekedjan den inträffar. Hela resan har inkluderats, från planering och biljettering till ankomst till målet för resan. Både positiva och negativa incidenter har inkluderats. Dessutom har händelser som föregått incidenten, samt reaktioner på incidenten (emotionella, kognitiva och beteendemässiga) samlats in. Deltagarna fick även ange i vilken grad varje incident påverkat deras sätt att resa. 78 av de totalt 470 insamlade incidenterna, hade lett till ett förändrat resande.

De incidenter som nämndes oftast, liksom de flesta av de allvarliga incidenterna, hade inträffat ombord på ett färdmedel samt vid stationer eller hållplatser. Incidenter i den fysiska miljön var särskilt vanligt förekommande, t ex brist på utrymme för rollator eller problem med hissar eller rulltrappor. Negativa incidenter nämndes oftare än positiva; 81% av alla incidenter var negativa. Även om de incidenter som påverkat deltagarna mest, det vill säga, lett till förändrat resande, oftast hänfördes till den fysiska miljön ombord på färdmedlet eller vid stationer/hållplatser, fanns även andra orsaker till förändrat resande. Exempelvis påverkade prisnivån, både negativt och positivt. Prissättningen framhölls som problematisk av vissa, då den upplevdes som krånglig, oförutsägbar och orättvis men sågs av ett mindre antal deltagare som en möjlighet att köpa billigare biljetter.

För att förstå varför vissa incidenter lett till förändrat resande för individen, bad vi också deltagarna berätta hur de reagerat på de olika incidenter de stött på. Vi fann att ett förändrat resebeteende kunde hänföras till fem olika teman;

1. *Faktiska begränsningar*, t ex att trappsteget in till tåget var för högt eller att information endast fanns på internet när man saknade dator. Detta kunde leda till resignation och ett konstaterade att resandet var omöjligt.
2. *Dynamiska faktorer*, oförutsägbara händelser kan ge upphov till en känsla av osäkerhet. Ett exempel som beskrevs är busschaufförer som ibland stannat långt ifrån trottoarkanten. Rädslan för att det ska hända kunde påverka vissa deltagares resande.
3. *Orättvis behandling*; långa köer, trånga vagnar eller komplicerad prissättning gjorde att vissa kände sig illa behandlade eller lurade, vilket kunde ta sig uttryck i förödmjukelse och ilska.
4. *Komplicerat resande*; flera barriärer efter varandra kunde skapa en tröskel som blev svår att ta sig över, även om varje incident för sig hade varit möjlig att klara. Det kunde gälla t ex anslutningsresor eller biljettering.
5. *Associerade tidigare erfarenheter*; för resenärer som tidigare utsatts för skrämmande händelser i samband med resor, t ex blivit förföljda eller antastade, hade händelsen lett till en ökad vaksamhet och hos vissa deltagare ett undvikande av resor, i synnerhet sena kvällar. Detta gällde främst kvinnor.

En gemensam nämnare för flera av ovanstående teman och en slutsats som kan dras av studien är att mer personlig assistans skulle kunna vara en av flera viktiga åtgärder för att hjälpa äldre personer till en mer förutsägbar och tillgänglig resemiljö. Det kan gälla allt ifrån hjälp med bagage eller elektroniska biljettautomater till vetskapen att det alltid går att få kontakt med personal om något oväntat problem skulle uppstå.

Mätning av barriärer

De försökspersoner som identifierats genom urvalsstudien graderar sedan den upplevda tillgängligheten för de olika barriärerna som tagits fram genom(ovan). Vi har använt oss av en invariant mätanalys, enligt Rasch, som korrekt hanterar ordinala mätvärden (t ex enkätsvar) samt ger mått på tjänsten (i detta fall, att leverera en tågresa) som inte påverkas av:

• förmågor eller attityder hos specifika personer som deltog i studien

• svårigheterna knutna till vissa test-items (t ex barriärer) som används i undersökningen [*Pendrill and Fisher*, 2014]

Rasch-analysen ger separata estimat – på en kvantitativ intervallskala – av varje persons förmåga och varje barriärs utmaningsnivå. I stora drag indikerar analysen att vissa grupper av barriärer, t ex att ergonomiska barriärer (Lätt eller svårt att komma av fjärrtåget/tågen), innebär en mindre grad av utmaning än informations- (eller kognitiva) hinder (Lätt eller svårt att ta del av informationen ombord på fjärrtåget/tågen).

Modellering av tillgänglighet

För att kunna mäta tillgängligheten behöver vi en modell för hur begreppet är sammansatt samt en modell för hur vi mäter. Det första steget handlar om att definiera begreppet som beskrevs under sektionen om process för mätningar av nya storheter. Vi behöver också bryta ner vårt begrepp tillgänglighet i sina olika beståndsdelar som kan vara lämpliga att mäta.

Vi har i detta syfte utvecklat en teoretisk människa - miljö – interaktionsmodell för tillgänglighet till järnvägstransporter [*Baird och Berglund*, 1989]. Modell A visar upplevd tillgänglighet som en funktion av resebeteende och barriär samt en persons funktionsnedsättning. En funktionsnedsättning anses vara en personfaktor, dvs inneboende i personen. Det kan påverka vilka begränsningar eller hinder som påträffas under resan. Istället för att fokusera på personers funktionella begränsningar, kan det vara fruktbart att fokusera på deras funktionsförmåga, som föreslås i modell B. Här kan vi se tillgänglighet som: (a) den resandes funktionsförmåga, (b) deras upplevda hinder i resemiljön, samt (c) sitt resebeteende.

I vår modell betraktar vi barriärer som miljöegenskaper som bedöms av resenären. Följaktligen kan den upplevda ansträngningen för samma barriär värderas olika för olika resenärer. För varje resenär beror vikten av en barriär på den upplevda ansträngningen när personen stöter på barriären. Om mer ansträngning krävs för en viss barriär behöver personens funktionella förmåga att vara högre än om det krävs mindre ansträngning. Dessutom är alla hinder inte lika vanliga på resor. Sålunda kommer sannolikheten att möta en specifik barriär vid en specifik resa också påverka den uppfattade tillgängligheten.

Vi använder en matematisk modell som beskriver mätning av tillgänglighet, *A*. Den baseras på vår interaktionsmodell och kan uttryckas enligt:

$$A_{i,j} = \prod_b [1 - p_{jb}\psi_i(d_b)]$$

Denna modell innehåller mätningar av den upplevda ansträngningen, ψ_i för personen *i* inför en viss barriär, d_b, och sannolikheten, p_{JB}, att en person kommer att möta barriären, d_b, på väg till destination *j*. Den uppmätta upplevda ansträngningen är en funktion av det sanna värdet, ϕ, och en felkomponent, ν, enligt.

$$\psi_i(d_b) = \phi_i(d_b) + \nu_{ib}$$

Den upplevda ansträngningen ϕ är definierad mellan 0 och 100%, och kan översättas till en tillgänglighetspoäng: $P_{success}$ =100%-ϕ på hur lyckad implementeringen av tågsystemet är (det vill säga att leverera ett gott resande). Genom att genomföra en Rasch-analys kan vi dela upp tillgänglighetspoängen $P_{success}$ i varje persons förmåga, θ, och varje barriärs utmaningsnivå, β, genom sambandet:

$$\log\left(\frac{P_{success}}{1 - P_{success}}\right) = \theta - \beta$$

I allmänhet, kommer dock det uppmätta värdet på *β* att skilja sig från det sanna *β'*, med ett mätfel ε_β enligt:

$$\beta = \beta' + \varepsilon_\beta$$

Denna invarianta mätanalys, som tillåter att utmaningsnivån *β* för en viss barriär kan uppskattas oberoende av vem som möter utmaningen, ger även möjligheten att identifierar en metrologisk normal för barriärutmaning. När en överenskommen definition och realisering av normalbarriären är etablerad, kan denna användas reproducerbart som referens för andra resesituationer. Liksom i mer traditionella metrologiska sammanhang ger tillgången till spårbara referenser alla fördelar av objektivt jämförbara mätningar.

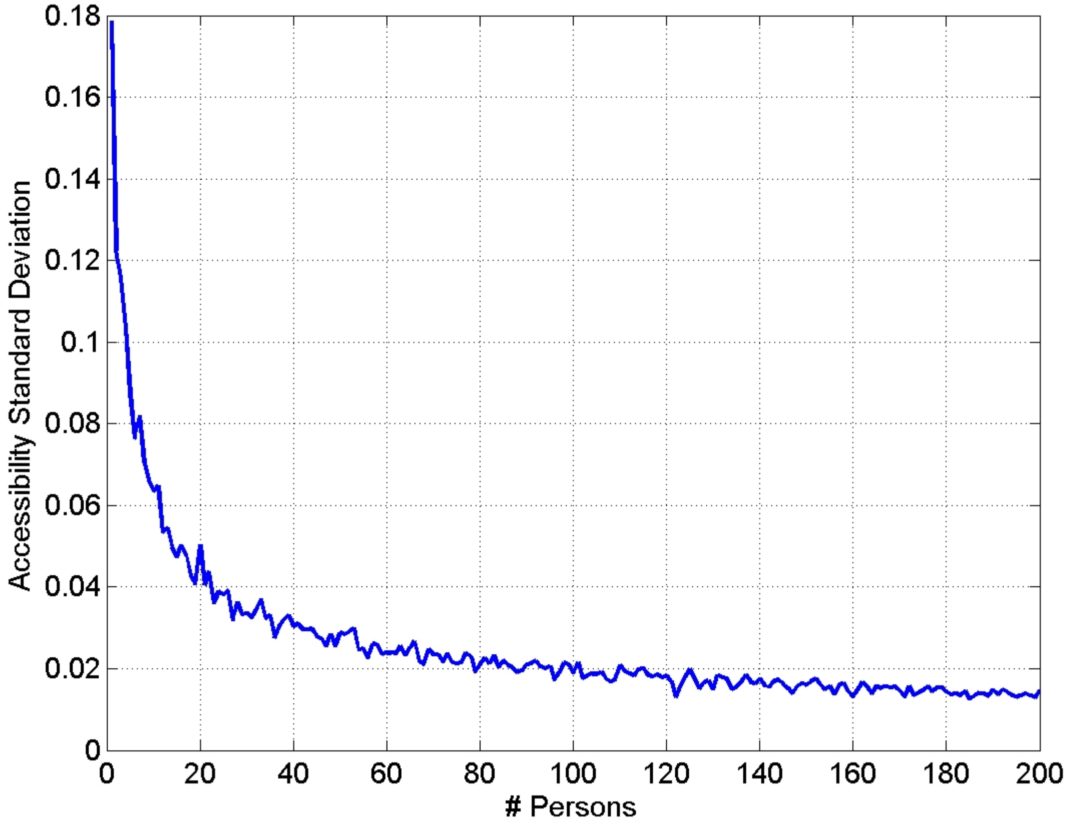
Efter kalibrering kan sedan det korrigerade värden för varje persons förmåga, θ, och varje barriärs utmaningsnivå, β, tillämpas i Rasch-uttrycket för tillgänglighetspoängen, $P_{success}$, som i sin tur kan korrigera mätningen av den upplevda ansträngningen genom $\psi_i(d_b) - \mu_{ib}$. Slutligen ges då hela resans tillgänglighet, korrekt kalibrering, av uttrycket:

$$A_{ij}^{m} = \prod_{b} \left[1 - p_{jb} \left(\psi_i(d_b) - \mu_{ib} \right) \right]$$

KOPPLING MELLAN MÄTNING, TILLFÖRLITLIGHET OCH BESLUTSFATTANDE

Baserat på simuleringen kan vi kartlägga hur stor gruppen av resenärer bör vara för att vara representativ för en större grupp. Vi har utför simuleringar med gruppens storlek varierad från 1 till 200 personer. För varje gruppstorlek genomförde vi 100 försök. Figur 2 visar standardavvikelsen för uppmätt tillgänglighet som en funktion av antalet personer i gruppen av resenärer. Medelvärdet för tillgängligheten för dessa simuleringar är cirka 0,3. För att ha en standardavvikelse av typiskt en tiondel av det uppmätta värdet behöver vi därför en grupp resenärer av en storlek på cirka 40 personer.

Rasch-analysen av de uppmätta person- och barriärattributen visar typiska värden för undersökningarnas tillförlitlighet R_β som ligger i storleksordningen 0,8 med en motsvarande separation av 3. Det innebär att cirka 75% av de observerade variationerna i mätningarna förklaras av sökta skillnader snarare än av mätosäkerhet. Värden i denna storleksordning anses vara acceptabelt för pålitlig beslutsfattande [*Linacre*, 2002]. Tillförlitlighetskoefficienten är relaterad dels till antalet testpersoner och dels antalet test-items, till exempel, genom Spearman-Brown predikteringsformeln. Framtida utmaningar kan ligga inom att modellera en optimerad mätosäkerhet genom att balansera kostnader för mätningar mot konsekvenskostnader för felaktiga beslut orsakade av mätosäkerhet [*Pendrill* 2010, 2014].



FIGUR 2 **STANDARDAVVIKELSEN FÖR UPPMÄTT TILLGÄNGLIGHET SOM EN FUNKTION AV ANTALET PERSONER I GRUPPEN AV RESENÄRER.**

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APPENDIX I

Overall Accessibility to Travelling by Rail for the Elderly with and without Functional Limitations – the Whole Trip Perspective, Sundling, C., Berglund, B., Nilsson, M., Emardson, R., Pendrill, L., to be submitted to Transportation Research part A.

APPENDIX II

Critical incidents in train travelling and their effects on travel behavior for older persons with functional limitations, Sundling, C., M. Nilsson, B. Berglund, S. Hellqvist, R. Emardson, L. Pendrill, to be submitted to Journal of Service Research.

APPENDIX III

Measurements of perception: accessibility in railway transport system for travelers with and without functional limitations, Sundling, Nilsson, Berglund, Pendrill, Emardson,"15 International Congress of Metrology" Paris, 2011.

APPENDIX IV

New perspective on the accessibility of railway transport for the vulnerable traveler, Sundling, C., Berglund, B., Nilsson, M.E., Emardson, R., & Pendrill, L., Journal of Physics: Conference Series, Vol 459, 012021, 2013.

APPENDIX V

Two Models of Accessibility to Railway Traveling for Vulnerable, Elderly Persons, C. Sundling, R. Emardson, L. Pendrill, M. E. Nilsson, and B. Berglund, submitted to Measurement.

APPENDIX VI

Measurement Of Accessibility To Rail Transport Systems , Emardson, R., P. Jarlemark, L. R. Pendrill, C. Sundling, M.E. Nilsson, B. Berglund, , Advanced Mathematical and Computational Tools in Metrology and Testing, vol.9 (F Pavese, M Bär, J-R Filtz, A B Forbes, L R Pendrill, H. Shirono, eds.), Series on Advances in Mathematics for Applied Sciences vol. 84, World Scientific, Singapore, 2012.

APPENDIX VII

Psychometric measurement and decision-making of Accessibility in public transport for older persons with functional limitations, intended for Measurement.

APPENDIX VIII

Literature Review on the Constructs of Usability, Disability and Accessibility - Especially in Relation to Railway Travel, C. Sundling.

APPENDIX I

Overall Accessibility to Travelling by Rail for the Elderly with and without Functional Limitations – the Whole Trip Perspective, Sundling, C., Berglund, B., Nilsson, M., Emardson, R., Pendrill, L., to be submitted to Transportation Research part A.

Overall Accessibility to Travelling by Rail for the Elderly with and without Functional Limitations – the Whole Trip Perspective

Catherine Sundling (a)
Birgitta Berglund (b)
Mats E. Nilsson (c)
Ragne Emardson (d)
Leslie Pendrill (e)

(a) Stockholm University, Department of Psychology, SE-106 91 Stockholm, Sweden, catherine.sundling@psychology.su.se
(b) Institute of Environmental Medicine, Karolinska Institutet, P.O. Box 210, SE-171 77 Stockholm, Sweden, and
Stockholm University, Department of Psychology, SE-106 91 Stockholm, Sweden, birgitta.berglund@ki.se
(c) Institute of Environmental Medicine, Karolinska Institutet, P.O. Box 210, SE-171 77 Stockholm, Sweden, and
Stockholm University, Department of Psychology, SE-106 91 Stockholm, Sweden, mnn@psychology.su.se
(d) SP–Technical Research Institute of Sweden, P.O. Box 857, SE-501 15 Borås, Sweden ragne.emardson@.sp.se
(e) SP–Technical Research Institute of Sweden, P.O. Box 857, SE-501 15 Borås, Sweden leslie.pendrill@sp.se

Corresponding author: Birgitta Berglund +468163857

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Abstract

Older persons' perceived accessibility to railway travelling depends on their functional limitations, their functional abilities and their actual travel behaviors in interaction with the barriers encountered during the trips. A survey was conducted on a random sample of 1 000 residents (65-85 yrs old) in the Stockholm County of Sweden (57% response rate). Railway accessibility was found to be good; only 10% were very discontented. The travel environment was perceived least accessible by respondents with more than one functional limitation, with restricted mobility or chronic pain, and with functional ability severely reduced. Those who travelled “often”, perceived the accessibility to be better than those who travelled less frequently. Among the respondents with high functional ability, travel costs and low punctuality were the two main barriers for travelling more frequently. For those with their functional ability most severely reduced, the own health was the main barrier. This research demonstrates that it is fruitful to operationalize the whole-trip concept as a chain of events set into motion, starting with existing functional limitations, barriers encountered, continuing with functional abilities and travel behaviors created, and potentially achieving overall accessibility to travel for all. Our research explicates the links among existing functional limitations/functional abilities, barriers encountered, accessibility and travel behavior. The results have practical implications for decision-making in the transport system, and deliver requested knowledge on vulnerable groups for an improved transport environment.

Keywords
Accessibility
Travel behavior
Functional limitation
Barrier
Railway travel
Older persons

1. Introduction

1.1 Transportation research

As the proportion of *the elderly* increases in the world, the transport systems must be improved to meet the requirements of this potentially vulnerable group. In the year 2060, almost 25% of the Swedish population is expected to be over 65 years old, as compared to 19% in 2011 (Statistics Sweden, 2012a). As people are expected to live longer, and also preserve an active lifestyle longer, the total number of journeys made by the elderly will increase. Concomitantly, the number of persons with functional limitations will increase with increasing age, and by then, many older persons would have acquired more than one functional limitation. So far, our current knowledge is limited regarding older persons’ travel behavior and specific travel needs. But, as every fourth person will be 65 years or older, the Swedish transport system will continuously be challenged to provide services, if not developed sustainably in time to meet the special needs for this age group (The Swedish Ministry of Social Affairs, the LEV project, 2012).

Research has shown that mobility, including accessible public transport, contributes to a better quality of life for many older persons. Accessible public transport can help older persons to stay mobile longer in life. Transportation would be important for visits to family and friends, for shopping and for physical exercise and sport events, among other activities (Linder, 2007). For example, to be able to reach desired people and places, comfortable means of transportation, and easiness getting on and off vehicles are highly valued characteristics. Conversely, uncomfortable vehicles could create pain in persons with movement and joint problems, for example, if they have to walk to distant bus stops or getting on and off busses without drop-steps. Research has shown that many older persons would like to engage in activities more often and transportation deficiencies present some of the main obstacles (Gabriel & Bowling, 2004, Farquhar, 1995, Su & Bell, 2009).

1.2 Research problem

The goal of this research is to investigate older persons' perceptions and experiences regarding accessibility in public railway transport, their actual travel behavior, their own various functional limitations and their level of functional ability, as well as the specific barriers they would encounter during trips (Fig. 1). Moreover, would the sort of functional limitation or the level of functional ability influence what kind of barriers a person would encounter, or affect his/her travel behavior? Another question is if the specific barriers encountered are associated with travel behavior. An overall goal is to be able to improve the accessibility to travel for the groups of travelers, who are often neglected in transport research, that is, persons with various sorts of functional limitations.

No definition of *accessibility* seems to be uniform and/or generally accepted. Gould (1969) described it as a slippery notion, one of those common terms that everyone uses until faced with the problem of defining and measuring it. The general key distinctions though, in the most recent definitions, are that accessibility is a joint attribute of people and places (Envall, 2007). Notably, we are here focusing on the passengers' perception of accessibility. Earlier research has shown that public-transport suppliers tend to overestimate the service quality provided as compared to the customers' perception and evaluation of it (Redman et al., 2013; Rietveld, 2005). Please note that the term *railway accessibility* here refers to the respondent's (one question) perceived access to travel, by train only. In our research, the term *overall accessibility* is regarded as a complex construct (see further Fig 1). It is composed of persons' *functional ability (functional limitations*, inclusive), the *barriers* they encounter in the transport system, and their self-reported *travel behaviors*. Moreover, we have adopted *the whole trip concept*; the trip is regarded as a chain of events, a *travel chain*, including everything from planning the trip to arriving at the place of intent (cf. Jensen et al., 2002).

A *functional limitation* is here defined as an inherently existing reduction in physical, psychological/behavioral or intellectual abilities (e.g., restricted mobility, vision or cognitive impairments). A functional limitation is thus a characteristic of a person as such. In the present research context, it should be separated from *functional ability* or *disability*, which is *not* a personal characteristic. The concept of disability has been internationally agreed upon to be "the product of an interaction between personal features and various characteristics of the environment" (see e g, WHO, 2013). Similarly, *functional ability* is here defined as the perceived level of functioning involved in person-environment interaction.

We define *barriers* as constraints in the travel chain, experienced by the individual passenger (cf. the whole trip concept adopted above). Travelling individuals will experience different kinds of barriers even during the same trip; however, some barriers might be common to all passengers during a trip. Over time, barriers can vary for the same individual because of changes in their functional limitations (e g, a fractured leg), attitudes to travelling, personal experiences, etc. Thus, barriers can vary among individuals and over time for the same individual. For example, if a barrier has already been encountered during a trip, it can also affect, adversely, the perception of additional barriers. Or, reversely, having encountered a barrier may in the future help a person to overcome it.

Here, *travel behavior* is here defined as the way people use different means of transport; we focus mainly on frequency of travelling and travel mode. In Sweden and many other countries, research have shown that the car is the most frequently used travel mode in the age group 65-84 years old. But, for this age group, car use declines with the increasing age of users, just as mobility does, in general. Measured in movements per day, car driving stands for 38% and being the passenger for 15%. There are differences though, within this age group, related to income and gender; persons with higher income and the men more often own a driver's license and a car. In comparison, only 0.7% of the journeys for this age group of old persons are made by long-distance train or 2% if underground and tram are included (Linder, 2007; SIKA, 2007; Alsnih & Hensher, 2003). In Sweden and internationally, the most common reason for older persons to travel is shopping. Physical exercise and recreational activities are also common (Linder, 2005, Wasfi et al, 2012).

Travel experiences and their meaning may differ among individuals. For persons with functional limitations, the various limitations may lead to different problems in the travel environment. Moreover, the severity of the same functional limitation as well as other factors, such as earlier experiences, would affect the experience and interpretation of the travel situation, and thus the person's perceived ability to travel. Similarly, older persons do not constitute a homogenous group (Alsnih & Hensher, 2003). Therefore, it is necessary to develop ways of measuring accessibility from the perspective of the individual travelers, with various prerequisites in the transport system. Presently, there is a shortage of measuring instruments for these users with varying functional abilities.

Our six main research problems concern public *train* travelling in short-distance and long-distance travelling, restricted to *elder* persons with and without functional limitations, all living in the County of Stockholm.

- To model *overall accessibility* grounded in travelers' functional ability, their travel behavior and the barriers encountered in the whole-trip travel environment.

1. To explore *railway accessibility* as related to functional ability, travel behavior and barriers in the travel environment for the elderly with and without functional limitations.

- To determine *functional ability* and its relation to kinds and number of *functional limitations/diseases* in the elderly.

- To determine *barriers* encountered in the whole-trip travel environment by the elderly with varying *functional ability* and kinds of *functional limitation/diseases*.

- To determine *travel behavior* in the whole-trip travel environment as a function of *functional ability* for elder persons with various kinds of *functional limitations*.

- To determine *travel behavior* as a function of *barriers* encountered for the elderly.

1. Method

In Figure 1, we propose a triangular model for conceptualizing *overall accessibility* to the whole trip, railway accessibility inclusive. Model A shows that functional limitations may influence what barriers are encountered in the travel environment and, therefore, also the travel behavior of the individual. Please note that a *functional limitation* is here regarded as a person factor, inherent in the individual, and thus, in the short term, "invariant" in relation to the environment, e.g. a broken leg or reading/writing disabilities are the same regardless of the situation. In contrast to Model A, Model B builds on three pairwise and reciprocal interactions. Moreover, the "invariant" construct functional limitation has been replaced by the "variant" construct *functional ability*. Please note that we are in this research focusing on the person's ability rather than her or his disability (cf. Sundling et al. 2013). Model B shows that barriers will influence functional ability as well as travel behavior. Barriers are here regarded as specific to each trip, and emerge from the person-environment interaction in the travel chain.

Insert Figure 1 about here

Figure 1. Accessibility may be modeled for travelers' functional limitations (Model A) or for travelers' abilities (Model B). Please note that functional limitation is invariant relative to travel behavior and the barriers, whereas abilities instead are variant owing to reciprocal interactions.

A person's functional ability is grounded in her or his functional limitations, other personal features and the environmental properties encountered. Thus the functional ability emerges in the person-environment interaction. It is fruitful to study how the abilities of persons with functional limitations might be improved in the context of person-environment interactions. If *barriers* are reduced or removed, the functional limitation is still invariant, but the functional ability may improve. As a consequence, resulting *travel behaviors* might be more flexible and independent. Therefore, our research aim at determining overall accessibility to travelling as a function of functional ability, barriers encountered, and travel behavior of persons with and without functional limitations. In spite of all effort to reduce barriers, especially for those with functional limitations, still we do not know what actions are most efficient for improving the ability to travel and establish independent travel behaviors.

In the present research, we have developed a questionnaire that is a prototypical measuring-instrument built on our accessibility model (Fig. 1). An overall goal is to pinpoint the most effective accessibility improvements in the transport system for persons with functional limitations and reduced functional ability. The “travel chain enabler” for *bus transport* is one of the few earlier instruments for measuring public-transport accessibility for persons with functional limitations (Iwarsson, Jensen & Ståhl, 2000; Jensen, Iwarsson & Ståhl, 2002).

We propose a triangular model in which the (perceived?) accessibility to railway travelling arises from interactive processes among three cornerstone constructs: travelers’ functional limitations (and/or their functional abilities), the barriers encountered in the transport system, and travelling behavior. Thus, each of these three constructs constitutes complex, multi-variable quantities (or patterns) among which interaction outcomes are of paramount importance for measuring the quantity *accessibility*. By reducing the barriers, the ability of travelling will be improved, and thus bring about more flexible travel behaviors.

Emardson et al. (2012) have created an accessibility measure for persons with functional limitations in which barriers during a trip have different weights for different persons depending on their functional ability and travel behavior. The measure provides the probability to face a certain barrier in travelling to a certain destination; that is, a measure of accessibility for the individual. The more weight placed on a certain barrier, the less probable is the particular journey. Moreover, functional limitations and functional ability are understood from the perspective of travelers' personal experience and interpretation. Thus, functional ability may differ among individuals even if their functional limitations are identical.

However, for simplicity we will not consider, in the following, that the perceived effort, if facing a barrier is affected by previously experienced barriers. Using the approach of viewing barriers as constraints in the travel chain, Equation 1 presents Emardson et al. (2012) model for accessibility (*A*) of one traveler (*i*) with regard to destination (*j*), as A_{ij}, that is, empirically measured (superscript *m*) in Equation 1:

$$A_{ij}^{m} = \prod_{b} (1 - p_{jb}\psi_i(d_b)) \tag{1}$$

where d_b is barrier number *b*, and p_{jb} is the probability to face barrier *b* when going to destination *j*. The symbol $\psi_i(d_b)$ is the *measured accessibility* indicated for each barrier. It is a real function operating on the set of barriers, and it is defined on a scale from zero to one, Emardson et al. (2012) have proposed and investigated, successfully, a multiplicative accessibility measure instead of an additive measure. The latter was used by for example, Weibull (1980).

$$\psi_i(d_b) = \phi_i(d_b) + \nu_{ib} \tag{2}$$

In (Eq. 2), we introduce an accessibility indicator, $\psi(d_b)$, which is a function ϕ operating on the barriers (d_b). This indicator of accessibility is defined on a scale from 0 to 1 (cf. Weibull, 1980). These scale values of, A_{ij},, denote *perceived effort*. Measures of accessibility can either be determined by observing the choice and effort expended (Measuring Man) or by measuring the perceived effort (Man as a Measurement Instrument) of each route, if facing a certain barrier. In our research model, we are focusing on each traveller's perspective and we have thus chosen the latter. For each barrier, there is also a certain probability of encountering it on a specific trip (p_{jb}). The symbol ν represents the measurement error and is a random variable, which is normally distributed with a mean value υ and a standard deviation, σ_ν . In applying our model, it is important that the barriers are scaled by a representative group of persons. This will guarantee the validity of our accessibility indicator. The weighting of barriers according to the model lies outside the scope of this paper. In the present research we explore how the underlying constructs of the formula interact for our target group.

2.1 Sample and Procedure

After approval from the local ethical committee in the Stockholm area, a pilot study was conducted in May-June 2011 in order to try out and improve the questionnaire that was to be used in the main study. The piloting involved a convenience sample of 22 persons (64-76 years old), all questionnaires were returned. The content and design of the questionnaire was improved according to these results. Main improvements involved the layout, clarity of language, and decreased number of response alternatives to make it easier for respondents to complete the questionnaire. More space was also made available for respondents' potential comments.

In November, 2011, the revised main questionnaire was sent out to a random sample of 1 000 persons (65-85 years old) living in the County of Stockholm, Sweden (its population is estimated to approximately 2 000 000). The questionnaire was mailed to each respondent's home address together with a reply-paid envelope. An introductory letter was attached, which contained information on the goal and content of the investigation and on voluntary participation.

Three reminders were sent out and the last reminder also contained a copy of the questionnaire. After three months, the data collection was closed. By then, 574 questionnaires had been filled in and returned, corresponding to an overall response rate of 57%. The questionnaire data were coded and analyzed statistically in SPSS version 20.0 (IBM, 2011).

2.2 Questionnaire

The questionnaire used basic demographic questions from recent Swedish surveys by Statistics Sweden. The larger part of our questionnaire on accessibility in elder persons' traveling was constructed by the authors specifically for the present study. The questionnaire was especially built for *whole trip* traveling and therefore the sets of questions were developed accordingly. The focus was on the measurement of the overarching construct of overall accessibility. In our research model, overall accessibility is regarded as an outcome of four constructs; functional limitations, functional ability, barriers and travel behavior (see Figure 1). Railway accessibility is introduced as a fifth concept constituting a partial construct of overall accessibility, which refers to the whole trip. We focused on the interrelationships among these five constructs and on their relationships to our sixth overarching construct; overall accessibility. For definitions, see below.

Demographic questions informed that out of the 574 respondents, 54% were women and 46% men. Thus, the gender split of respondents agrees with the gender distribution in Stockholm County (Statistics Sweden, 2013). The mean age of our respondents was 73 years, and the standard deviation 5.8 years. Table 1 shows that most respondents were retired (in all 95%): 32% reported living alone, 58% with a spouse, and 8% with a spouse and child/children. Largely reduced functional ability was more common among the women than the men, and among the older respondents ($\geq$ 73 years old) as compared to the younger ones (65-72 years old). Notably, those with low income had to a higher extent reduced functional ability. This outcome is on a level with earlier enquiries (Statistics Sweden, 2012 b). Notably, five of our respondents with mobility service reported that they had no reduction at all in their functional ability. A plausible reason might be relapsing illnesses. We chose to use Cramér's

V as statistical effect-size measure of association among variables. It is commonly used for data in larger than two by two matrices, and it takes into account the degrees of freedom.

Table 1. Demographic characteristics of the random sample of persons 65-85 years in Stockholm county (N=574).

Insert Table 1 about here

2.3 Six Main Constructs and their Measurement

The main part of the questionnaire focused on the *barriers* encountered in the public transport environment in general, and especially in the railway travelling environment, including travelers' past experiences and their expectations for future travelling. Another important part of the questionnaire investigated the travelers' *functional limitations*, their own (perceived) *functional ability*, their use of assistive devices (e g a cane or glasses), and mobility service (i e, Swedish Färdtjänst). The third central part of the questionnaire researched actual *travel behavior*. The six constructs taken together, constitute the measurement model of *overall accessibility.* One question addressed accessibility in train traveling specifically, here denoted *railway accessibility*.

- *Railway accessibility:* The perceived railway accessibility was measured in one question (5-category scale).
- *Functional limitations*[1]*:* Self-reported functional limitations/diseases were assessed by one question (15 alternatives). Here, functional limitation/disease refers to a medical diagnosis or symptom. Three additional questions assessed authority-evaluated needs, e g mobility service, disabled parking permit and a 9-alternative question.
- *Functional ability*[1]*:* Self-*reported* degree of functional ability and health status (5-category scales). Functional ability refers to the self-reported *severity* of one's functional limitation(s) or disease(s).
- *Travel behavior:* Actual travel behavior was measured with questions on travel frequency, mode of conveyance, destination, purpose of trip, ticket purchase, luggage brought, travel companion(s), and change of transportation means.
- *Barriers:* The main part of the questionnaire measured the perceptions of specific barriers in the travel environment encountered during *the whole trip* (i e the whole travel chain, door-to-door). Subsections were: (a) long-distance train travelling, (b) train travelling in general, and (c) public transport, including other transport means than train.

2. *Overall accessibility:* Together, the five constructs presented above (railway accessibility, functional limitation, functional ability, travel behavior, and barriers) would constitute the construct "overall accessibility" to whole-trip travelling.

We focused on a densely populated geographic area, the County of Stockholm, Sweden. As most

[1] It may be argued that authority-evaluated needs would be a more "objective" way of assessing functional limitations and functional ability. But, in the present research we attach great importance to *self-reports*, because the respondents' decisions regarding their travel behavior and earlier experiences in the travel environment must depend on their own appraisal of their functioning. Thus two persons with the same functional limitation may experience the travel environment differently, and consequently also their needs. Therefore, they may draw different conclusions leading to different behaviors.

travel environments, the Greater City of Stockholm is invariably changing depending on season, construction work, and larger events, etc. The questionnaires were sent out in November 2011 and most of them were returned in November and December. The data collection closed on February 1, 2012. During the data collection, a large rebuilding project at the Stockholm Central Station was going on. This might have influenced, for instance, the ability to move around inside the station and affected information retrieval and orientation somewhat.

3 Results of Questionnaire Study

This section presents the results for six constructs; railway accessibility, functional limitations, functional ability, travel behavior, the barriers and closes with overall accessibility. First, we will report on each construct separately, followed by descriptions of how functional limitations influence the other constructs and how the latter are interrelated.

3.2 Functional Limitations

The most commonly reported functional limitations were vision impairment (22%), hearing impairment (21%) and cardiovascular disease (17%). Consequently, the most frequently used assistive aids were glasses or lenses (76%). Rank-order coefficients of correlation among the various kinds of functional limitations/diseases were generally low; most Spearman's ρ-values were below 0.30; the three highest statistically significant coefficients were, for $p = 0.01$:
(a) cognitive deficits in attention/memory/concentration *and* reading/writing/speech (0.40),
(b) musculoskeletal impairments with chronic pain *and* reduced physical mobility (0.39), and
(c) sensory impairments regarding hearing *and* vision (0.32).

As expected, our younger of the old participants (64-74 years) had fewer concurrent *functional limitations/diseases* (see Table 3 for all choices of functional limitations/diseases) than our older group of participants (75-85 years). A larger part of the less old ones reported no or only one functional limitation/disease, whereas the older participants more frequently reported two or more (significantly different for $p = 0.005$ in multiple regression). No significant difference in number of concurrent functional limitations/diseases was found for gender.

All coefficients of correlations between the age of the participants for each of 15 kinds of functional limitation/disease were below $r = 0.30$**.** We have used the Pearson's coefficient (*r*) whenever responses were given on interval scales or ratio scales. The highest coefficients of correlation with age were found for restricted mobility ($r = 0.22$), attention/memory/concentration ($r = 0.18$) and reading/writing/speech ($r = 0.12$). These correlations were all statistically significant for $p = 0.01$.

A Principal Component Analysis (PCA) was conducted on the inter-correlation matrix of the prevalence of 15 functional limitations/diseases for the participants. The aim of this analysis is to find out if there are underlying patterns of association among the various functional limitations/diseases of the subjects. Table 2 shows the 7 components of the PCA, extracted for eigenvalues > 1. Together, these components explain 60% of the total variance. There are two sets of components: C1-C3 that refer to functional limitations and C4-C7 to diseases. The first principal component (C1) is dominated by cognitive, language and mental symptoms (mental ill-health included), the second (C2) constitutes chronic pain and restricted mobility (neurologically associated condition, inclusive), and the third (C3) consists of the two main sensory impairments: hearing and vision; diabetes may contribute to this component because of visual deficits. Among the diseases, the forth component (C4) consists of cardiovascular and lung-associated diseases. Neurological disorders, epilepsy inclusive, constituted the fifth component (C5), systemic diseases (rheumatic disease and diabetes) the sixth (C6) and, finally, travel sickness represents the seventh component (C7) alone.

Table 2
Principal Component Analysis of Functional Limitations/diseases.

According to our questionnaire study, 8% of the respondents had by the authorities been declared to be in need of mobility service (Sw.”Färdtjänst”, a taxi service for persons with functional limitation/disease). This is a low figure for our sample of older persons (age 65-85 yrs) because as many as 5 % of the Swedish population are getting such service (Börjesson, 2002). Moreover, 3% of our respondents were found to have a disabled parking permit.

Table 3
Overall perceived reduction in functional ability cross tabulated against the kind of functional limitation/disease.

Table 4
Perceived overall ability as a function of the number of functional limitations/diseases (N0555, Cramér's V = 0.429, p 0.000)

Functional Ability

Among 571 respondents (out of 574 possible), 67 % reported that their general health was “good or very good” (on a 5-point scale from very good to very poor) if compared to others of the same age. This stands comparison with the 63% in Statistics Sweden’s survey for the age group of 65-84 years (Statistics Sweden, 2012b). Similarly, most of our respondents (57%) reported having “no reduction” in their *functional ability* (on a 5-point scale from not reduced to extremely reduced). There is no significant gender difference. Only 5% of the respondents reported their functional ability as ”very reduced” or ”extremely reduced”, a reduction found to be more common among the women than the men.

3.4 Barriers

The questionnaire mainly focused on train travelling, including the underground, local trains (incl. trams), commuter trains and long-distance trains. But, it also included questions on public transport in general, because different means of transport are often involved in the same travel. Notably, only one barrier encountered in the travel chain can critically affect the whole journey. Therefore, questionnaire questions combined would address the whole journey, constituting a travel chain. One section of the questionnaire addressed specifically long-distance train journeys.

Travelling by train in general. What kind of barriers had the *train-travelling* respondents encountered? In our open questions, the most frequently reported barriers were found to be: (a) delays and other time-matters of train travel, (b) shortcomings in the physical environment, and (c) shortcomings in the information available. The most frequently suggested improvements to the travel experience concerned time aspects**.** These included wishes for more frequent departures and better punctuality, for example, through improved snow clearance. Not only time-saving journeys were called for, conversely, some respondents wanted more time available at the stations, such that they did not need to rush when boarding.

Physical travel-environment. In open questions, many respondents proposed how to improve the physical environment onboard the train and/or in station areas. More personal space onboard, such as seats for all passengers or more space between seats, pleasant temperature in trains and waiting rooms, as well as more escalators, are examples of wished improvements of the physical travel environment. Many wished improvements concerned the service at stations and onboard, for example, more staff available to help out with luggage and/or food and drink, especially better food quality, more to choose from, or table service, because balancing food and drink in full speed trains can be dubious.

The weather. The weather was found to affect 30% of the respondents (often or sometimes) in deciding whether they would travel by train or not, although not being affected by the weather at all was equally common (32%). Those who would like to travel by train more often were slightly more affected by the weather (41%) than the other respondents.

Long-distance travel chain (the whole trip). One section of the questionnaire was devoted to barriers perceived during different parts of the travel chain of the very latest long-distance train journey: from the planning of the trip to reaching the destination. The participants were asked how easy or difficult it was to use the travel environment, and they could also contribute with comments. In this section, results are presented in the order of importance according to the respondents. Thus, the parts of the travel chain that most of the respondents found problematic are presented first. Overall, most respondents who had been travelling the last year had found it easy to travel. Figure 1 shows the distribution of barriers they had encountered in the travel environment. The most frequently reported barrier was the inability to obtain information at the stations: 15% found it relatively difficult or very difficult to retrieve such information. More staff and improved visual information was requested. Main complaints were about inconsistent information or signs that were out of order.

Because of inadequate information, ongoing reconstruction work at stations and long distances within station areas, 12% found orientation and movement within station areas difficult. Moreover, 10 % experienced difficulties getting onboard the train and the main concern was to be able to climb high steps into the train with luggage.

Figure 2. Barriers in long-distance train travelling experienced by respondents who travelled by long-distance train last year (n=145.).

Better/Improved information during the planning stage of the journey was wished, for example, because of difficulties in understanding the ticket system. Moving around inside the vehicle was perceived to be difficult because of insufficient stability in the moving train because of vibrations, jerkiness, etc. When getting off the train, again the high steps constituted a barrier for carrying luggage but also because of nonexistent or unhelpful staff.

Regarding information onboard the train, loudspeakers were the main cause of discontent; the sound being too hard to hear, too loud or simply out of order. A long wait for ticket purchase or too few choices for seat reservations or kinds of credit cards accepted are all examples of complaints from those who found ticket purchase difficult. Some respondents had experienced inconveniences because of lavatories that were closed, dirty, or nonfunctional or because they were lumbered of luggage. Moreover, concerning personal service from staff during the journey only 4% found the service unsatisfactory, however, mainly because of absence of staff.

Lower ticket price was considered to be the most important factor for choosing to travel more often by long-distance trains. If it would have been less expensive, 62% said they would travel more often, followed by *punctuality* (keeping the schedule and arriving at destination on time). Other factors, for example the possibility to travel at other hours, other passengers' attitudes or not having to travel under the ground level were all less important. A complete list of alternatives, presented to the respondents, is shown in Appendix 1.

3.3 Travel behavior

On average, the respondents travelled 23 days per month[2] (notably, 29% of the respondents missed

2 Sum of days per month traveled with each means of transport.

this question). The travel means included long-distance and short-distance trains, buses, airplane, boat, and car, taxi inclusive, as well as mobility service. Respondents scaled travel frequency on a 5-point category scale (“never” to “4-7 days per week”). For each kind of transport, we have calculated *travel frequency* as “the sum of the number of days per month travelled”. The respondents who had omitted one or more of the sub-questions (travel means) were excluded.

Train travelling. The respondents were found to travel on average 7 days per month with train. Our concept “train travelling” includes underground, commuter trains, trams, local trains, and long-distance trains.

Car use. For the group of respondents as a whole, car was the most frequently used travel mode: 93% travelled by car at least occasionally and 36% used it 4-7 days per week. A majority of the respondents had both driver’s license and a car in the household (see Table 1). Of those who responded to both these questions (driver’s license *and* car ownership), 92% of the men and 71% of the women owned a driver’s license, but 78% of the men and only 49% of the women had a car in the household. Thus, fewer women than men could independently use a car in the household. Although most respondents travelled by car as driver or passenger, at least occasionally, a majority of our respondents (77%) also used public transport often enough to have acquired a discount card.

Local bus and the underground. Apart from the car, local bus was the most frequently used means of travel, followed by the underground.

Long-distance bus and aircraft. Long-distance bus was the least used means of transport, indeed 76% of the respondents reported never using it. Most of the respondents (66%) also travelled by air, occasionally.

Long-distance train. More than half of our respondents, 61%, never travelled by long-distance train (see Appendix 2 for a list of all travel means included in this question). Moreover, most of our respondents (all 65-85 years old) had not recently been travelling by long-distance train. Therefore, the part of the questionnaire concerned with the long-distance train journeys during the last year only involved 145 persons (or 25% of all respondents). Our respondents with no car in the household or with high income were more likely to have travelled by train during last year than those with a car or with lower income (odds ratio were 3.5 and 2.1, respectively).

Travelling abroad. Most of the respondents travelled abroad at least once in a while. Only 13% responded that they never travelled outside Sweden. But, during the last year, most of the respondents (86%) had *not* made a long-distance journey or journey abroad. Of those who had, the majority had travelled “by car” (60%), followed “by air” (48%) and/or “by train” (28%). The respondents were asked what transport mode they normally used; “by air” was the most common answer (81%) for travels abroad or long-distance journeys.

Buying tickets. Ticket purchase was made most commonly at a staffed point-of-sale (83%), followed by the Internet (59%) and by telephone service (42%). Ticket-machine (26%) and cell phone (10%) purchases were least common. The percentage of missing answers was high for these questions, that is, up to 43%. Still, it is worth noticing that in our group of 65-85 years old, staffed point-of-sale was most preferred.

3.1 Railway Accessibility

A majority of the respondents (59%) considered accessibility to train travelling to be very good or fairly good. Conversely, 10% thought it was very bad or rather bad. According to 31%, it was in between. Among all respondents, 41% would have liked to travel by train more often if it were possible. This view was more common among the respondents without (45%) than with functional limitations (34%), but this difference is not statistically significant.

Relationships among constructs

In the next section, we present relationships among four of the targeted constructs for respondents with and without different *kinds* of functional limitations/diseases. These four constructs are the *level* of functional ability, the barriers encountered, travel behavior and railway accessibility in travelling.

Functional Limitations/diseases and their relation to Functional Ability

As shown in Table 3, some functional limitations or diseases were more often associated with serious reductions in functional ability than others. Respondents with restricted mobility or chronic pain reported that they had reduced functional ability to a higher extent than, for example, the respondents with impaired vision or hearing.

Table 4 shows that respondents with more than one *functional limitation* reported their overall functional ability to be lower than those with “no or only one” functional limitation (or disease). A majority of the participants, who have “no or only one” functional limitation, reported having no reduction in their functional ability, whereas most of the respondents with two or more functional limitations report that they had somewhat or very reduced functional ability. The level of functional ability was measured in a direct question on perceived ability. Notably, we chose to focus on perceived ability as it is a direct measure, and also because some of the respondents “without functional limitation/disease” responded that they had “a reduced functional ability”. This was logically possible because of the fixed number of response alternatives for the functional limitations/diseases in the questionnaire. Respondents may thus have suffered from other kinds of health problems.

Functional Limitations/diseases and their relations to Barriers

Regarding the barriers in different parts of the latest journey with long-distance train, the most commonly reported barrier was “inadequate information at stations”. However, different kinds of barriers naturally dominated among the different kinds of functional limitation/disease. Thus, persons with neurological diseases found it particularly difficult “to move around onboard the long-distance train” ($r = 0.46$), as did also persons with restricted mobility ($r = 0.31$). Neurological and rheumatic diseases also implied “moving problems within the stations” ($r = 0.32$). Because of the limited number of respondents, these between-group comparisons should be cautiously interpreted.

Regarding specific barriers for travelling more often with long-distance trains, there were no secured associations with respondents’ types of functional limitations (see Appendix 1 for the complete list of 30 barriers).

Functional Limitations/diseases and their relations to Travel Behavior

Travel frequency was generally weakly correlated with the sort of functional limitation/disease (Pearson’s r). Having restricted mobility or problems with attention/memory/concentration was negatively correlated with travel frequency ($r = -0.14$ and $r = -0.12$), respectively), all significant at the $p = 0.01$ level. Having reduced vision and travel frequency ($r = -0.13$) correlated reversely but significantly with each other at the $p = 0.05$ level. Also in previous research by Davidsson (2001), persons with restricted mobility and vision impairment have been reported to travel less frequently. Ta med SPSS-manualen.

Also, the kind of functional limitation was not important for “having traveled or not during last year by long-distance train" (shown by logistic regression).

Functional Limitations/diseases and their relations Railway Accessibility

Railway accessibility was reported to be lower by respondents with restricted mobility or chronic pain than for the others (Spearman $\rho = 0.14$ and 0.12, respectively). Although low, these coefficients of correlation are significant at the $p = 0.01$ level. For those with mental ill-health and epilepsy, the coefficients of correlation ($\rho = 0.10$ and 0.09, respectively) were significant at the $p = 0.05$ level. For persons with other functional limitations/diseases, no significant correlations with railway accessibility were obtained.

3.6.1 Functional Ability and its relation to Travel Behavior

A main result on train travelling is shown in Figure 5, that is, with travelers' improved functional ability, the average travel frequency per month will increase (all travel means combined)[3]. This result indicates that the *lower* the functional ability of the potential travelers, the *higher* the probability that their travel frequency will go down. The same pattern of results is found to be true for train travelling separately, Figure 6. In both these figures, the ordinate shows mean travel frequency per month with 95% confidence interval indicated.

Respondents with the lowest degrees of functional ability (very reduced and extremely reduced) travelled 10 days per month with all travel means combined or 2 days per month by train only. This travel frequency should be compared to 26 or 8 days per month, respectively, for the respondents without reduced functional ability. Accordingly, respondents, who considered their functional ability to be high, had more often taken long-distance train trips last year than those who reported that their functional ability was low. Among the respondents with very or extremely reduced functional ability, only 9% had the last year been travelling with long-distance trains, as compared to 31% in the group without reduced ability. For those with reduced functional ability, it was also more common to have travelled last year by long-distance train, if they had a car available in the household (odds ratio 2.2); but, income level was not a significant predictor for our age group of old persons.

Figure 5. Mean travel frequency as days per month travelled with all travel means combined as a function of functional ability. The travel means were: long-distance and short-distance train, bus, airplane, boat, and car, taxi inclusive as well as mobility service.

Figure 6. Mean travel frequency in days per month travelled on rail with various kinds of trains combined (long-distance train, commuter train, the underground and local train), as a function of functional ability.

Regardless of functional ability, the most common purpose of the *last journey* was "to visit relatives or friends" for the respondents who had travelled by long-distance train last year (64% for those without reduction and 56% for those with reduced ability). The second most common purpose of the last journey was "entertainment, culture and sport, and other events" for those without reduced ability (21%) and "tourist trip" (21%) for those with reduced ability. The third most common answer for those without reduction was "work or studies" (16%), while those with reduction reported "entertainment, culture, sport" (13%).

For the group of respondents without reduced functional ability, arithmetic mean travel distance was 478 km and arithmetic mean travel time 4 hours. For those with reduced ability, corresponding

3: Long- and short-distance trains, bus, airplane, boat, and car, taxi inclusive, as well as mobility service.

arithmetic means were for travel distance 648 km and for travel time 25 h, but with a median of 4 h (comparable to the group without reduced ability). The reason for the large difference between the arithmetic mean and median for those with reduced ability is caused by the very wide range and skewed distribution for travel time. The destination of the latest journey had mostly been within the country, in this case Sweden: 93% for those without and 90% for those with reduced functional ability. The latest journey had also been without heavy luggage (78% for those without and 69% for those with reduced functional ability) and without children under the age of 6 (99% for those without and 100 % for those with reduced functional ability). Most respondents travelled alone (59% for those without and 54% for those with reduced functional ability), whereas 37% of those *without* and 46% of those *with* reduced functional ability travelled with relatives or friends. Notably, only1% of those *with* reduced functional ability travelled with a companion. Most persons (65% of those *with* and 69% those *without* reduced ability, respectively) changed their means of transport during their latest long-distance train journey. The car was the most commonly used connecting mode (59% of those *with* and 44% of those *without* reduced ability, respectively) followed by bus (40% and 41%, respectively). The most frequent way of getting *to* and *from* the railway stations was by train; 55% and 62%, respectively (including subway, commuter train, and local train/tram).

To summarize, there was a tendency that respondents *with reduced functional ability* to a lesser extent had travelled to work (or study) on their last journey, but, notably, they had more often made a tourist trip, instead. They had also, to a higher extent, travelled with relatives or friends and with heavy luggage.

Functional Ability and its relation to Barriers

For respondents with a *high functional ability*, the concepts "price" and "time-keeping" were the two most important barriers for travelling more often with long-distance trains (see Appendix 1 for the complete list of 30 barriers): 62% (292 persons) said they would travel more often if it became less expensive to travel. Price was also important for persons with low functional ability (41% or 9 respondents). In the higher functional-ability group, 50% (226 persons) would travel more often if departure and arrival times were to be kept (23% or 5 persons in the low functional-ability group, $p = 0.043$, Cramer's V= 0.16). However, for the respondents with "low/extremely low" (50% or 11 respondents) compared to those with "high" functional ability (19% or 88 respondents), "to be healthier" was regarded as the most important prerequisite for travelling more often ($p = 0.002$, Cramer's V = 0.16). This association was not secured for any of the specific functional limitations/diseases researched.

3.5.1 Functional Ability and its relation to Railway Accessibility

Railway accessibility was reported to be slightly higher by the respondents without as compared to those with reduced functional abilities, 62 % compared to 56%. None of the (only) three respondents with "extremely reduced" functional ability found the railway accessibility to be good (Figure 3). Logistic regression showed that perceived railway accessibility could not be explained by age, gender, income, or car possession. Among those respondents who had mobility service (n=43), 19 respondents perceived railway accessibility as "neither good nor bad", whereas 6 respondents reported it to be "extremely poor" or "rather poor".

Figure 3. Perceived accessibility as a function of functional ability.

For respondents with neurological disease, chronic pain, restricted mobility, diabetes, and vision impairment, significant correlations were found between the respondents' perceived railway accessibility and their self-reported degree of functional ability (Table 4). Particularly those, who reported their functional ability to be low, also scaled their railway accessibility to travelling to be low. Although few respondents, those with neurological diseases had the highest coefficients of correlation between railway accessibility and degree of functional ability ($\rho = 0.85$); the group of persons with chronic pain or with mobility impairment both produced significant coefficients of correlation ($\rho > 0.30$).

Table 4. Spearman coefficients of correlation between perceived
railway accessibility and functional ability for persons with and without different functional limitations/diseases.

A majority of the respondents, who had not been travelling by long-distance train during the last year, thought it would be possible for them to travel if they would have liked to. Thus, 91% of those without reduced functional ability, and 78% of those with reduced functional ability, considered it to be possible for them to travel. Those who reported it to be impossible to travel were 2% and 6%, respectively. Logistic regression indicated that respondents who used a walking aid (walker, wheel-chair or crutches) or a hearing aid were more likely to perceive railway accessibility as rather poor or extremely poor (odds ratio 3.21 or 2.59, respectively) as compared to those who did not have that kind of handicap aid. Railway accessibility was unrelated to the other handicap aids (e.g. cane, glasses or lenses). Moreover, *restricted mobility* was also associated, but weakly, with not being able to travel by long-distance train (Spearman $\rho = 0.26$, $p = 0.01$). For $p = 0.05$, significant coefficients of correlation were also found for epilepsy ($\rho = 0.13$), diabetes ($\rho = 0.11$), and chronic pain ($\rho = 0.10$).

3.6.2 Travel behavior and its relation to barriers

Regarding long-distance trains, some of the desired reductions in barriers (30 in all) for traveling more frequently were weakly associated with frequency of *train travelling*. There was a tendency that those, who travelled more frequently, would travel even more often if the "perceived" existing barriers were to be removed. The barriers most highly associated with travel frequency were "shorter travel time" ($r = -0.22$) and "easiness of buying tickets for the whole journey" ($r = -0.20$), both significant for $p = 0.01$.

If the same set of our 30 barriers were correlated pairwise with travel frequency for *all travel means combined*, trains inclusive, only one of the barriers produced a coefficient of correlation, above $r = 0.20$; namely, "Becoming healthier and therefore being able to travel" ($r = 0.24$, $p = 0.01$). In this case, it was the respondents who traveled more infrequently, who said they would like to travel more often, if their health would be better.

The weather influenced some of the respondents' train travelling. We found that those, who reported railway accessibility to be high, were also more influenced by the weather in traveling as compared to those who reported it to be lower. Also, those who frequently travelled by train were more influenced by the weather. This concerned only the trains, because there was no or low associations with the weather if all travel means were included in the data analysis.

3.5.2 Travel behavior and its relation to railway accessibility

The participants, who reported railway accessibility to be high, were also travelling by train more often (Spearman $\rho = -0.29$) than those, who reported it to be lower. This was true also if other travel means were included ($\rho = -0.21$). Both coefficients of correlation are statistically significant at $p = 0.01$. There was no association between how often the respondents travelled (either by train or by all travel means combined) and whether or not they would have liked to travel by train more often if it would have been possible. Railway accessibility was weakly associated with choosing the train as transport mean for journeys abroad ($\rho = -0.12$, $p = 0.01$).

Figure 4. Mean travel frequency (95% CI) in days per month travelled with train(s) as a function of railway accessibility, as perceived.

3.5.3 Barriers and their relations to railway accessibility

Railway accessibility was positively correlated for all the questions regarding the barriers encountered during different parts of the latest long-distance train journey (Spearman $\rho = 0.32 - 0.47$, all significant at $p \leq 0.01$). The weather was also weakly, but significantly ($p = 0.01$ level), correlated with overall accessibility ($\rho = 0.16$). Those who were influenced by the weather, found the railway system more accessible.

The rank-order coefficient of correlation (ρ) was generally low, and not significant, between railway accessibility and each of the barriers for travelling more often. Railway accessibility correlated with the number of barriers; the coefficient of correlation was low ($\rho = 0.26$), but significant at $p = 0.01$. This result would mean that those potential travelers, who perceived railway accessibility as low, also, to a greater extent would not have traveled by train more often even if the travel environment would have been changed. Wanting to travel more often with train was not highly associated with any specific barrier encountered. Information at stations had the highest correlation with “wanting to travel more often with train”: $\rho = -0.199$, $p = 0.05$.

4.1 Conclusions and discussion

Most of the respondents reported having a good functional ability but 5% had severe reductions. The most common functional limitation was vision impairment. On average, respondents travelled 23 days per month (all travel means included[4]). Car was the most frequently used transport means. Less expensive tickets, better punctuality and better information were the most frequently chosen factors that would make respondents travel more often by long-distance train. Railway accessibility was regarded as good by a majority of the respondents, but 10% were very discontent.

1. In our sample of elderly, ca. 25% reported that they had no functional limitation: among the 15 listed, “restricted mobility” and “chronic pain” are the two that were most frequently associated with serious reduction in functional ability. Persons with more than one functional limitation/disease reported their functional ability to be lower than those with “no or only one” functional limitation (or disease). For certain kinds of functional limitations (neurological disease, chronic pain, restricted mobility, diabetes and vision impairment), perceived level of railway accessibility correlated with degree of functional ability.

2. Various barriers dominated among the travelers with the different kinds of functional limitations/diseases. For example, persons with neurological and rheumatic diseases and those with restricted mobility found it difficult to move around onboard long-distance trains or within stations. No other associations were established between specific barriers and the kinds of functional limitations/diseases.

3. Among the respondents with the most severely reduced functional ability, it was more common to attribute the barriers to one's own health.

4. Travel frequency was found to intercorrelate weakly with the three kinds of functional limitations/diseases but at a statistically significant level for restricted mobility,

4 Long- and short-distance trains, bus, air, boat, and car, taxi inclusive, and mobility service.

attention/memory/concentration and vision impairment.

5. Respondents with severely reduced functional ability travelled less frequently than those with better functional ability.

6. A lower perceived *railway accessibility* was found for some of the functional limitations, especially restricted mobility and chronic pain. Respondents with either more than one functional limitation/disease reported *the railway accessibility* as lower than the remaining respondents.

7. With lower functional ability, the *railway travel environment becomes less accessible*. Also, the respondents' level of functional ability was associated with perceived level of railway accessibility; those who had a higher ability also found the travel environment more accessible than those who had a lower functional ability.

8. Shorter travel time and easiness of buying tickets for the whole journey, were more important for the frequent travelers than for respondents who travelled more occasionally; although the coefficients of correlation were low.

9. For the latest long-distance train journey, railway accessibility was weakly correlated with all barriers encountered during different parts of the whole trip, the weather inclusive. Those who perceived railway accessibility as low, also to a higher extent said they would not travel by train more often in the future even if the travel environment was improved.

10. Respondents, who perceived railway accessibility as high, also reported that they traveled more often than those who reported it to be lower. That is, the higher the travel frequency the higher is the railway accessibility.

11. Functional limitation, level of functional ability, travel behavior, barriers encountered, and perceived **railway accessibility** were all associated, at least in part, though the coefficients of correlation were low.

4.2 Discussion of conclusion points

WHO defined the concept of disability as a product of the interaction between individual features of a person and individual characteristics of the environment (WHO, 2013). Disability may refer to anything from inaccessible information, staircases-and-doorsteps, to persons' attitudes. Therefore, the very same functional limitation may become a disability in one environment, but not in another. Moreover, disability and functional limitation should be understood from the perspective of the individual traveler's personal experiences and interpretations, because these may differ among individuals even if their functional limitations, and additional disabilities, are of the same kind and severity.

The findings of this study suggest that the respondents' perceived functional ability, and at least for persons with some kinds of functional limitations, will affect: (a) how they perceive railway accessibility, (b) what barriers they encounter during door-to-door trips, and (c) their travel behavior. Moreover, the extent to which our respondents found the railway travel environment accessible was associated with how often they traveled. Thus, railway accessibility and travel behavior can be thought of affecting each other. Those who find a travel environment accessible may be inclined to travel more often, but travelling more frequently would also help to overcome potential barriers in the travel chain, e g, ticket machines, scarce information and high steps of carriages. Many of the frequent train travelers, often also high in functional ability, would travel even more by long-distance train, primarily, (a) if travel time would be reduced and (b) if tickets for the whole trip would be possible to buy at the same time. These two associations were not identified in the case when all travel means were included. In that case, only the respondent's *own health* was significantly correlated with the wish to travelling more oft with long-distance train. In this case it as those respondents who travelled more infrequently, who said they would travel more often if their own health would have been better. Since train only is a subgroup of all travel means, and thus, also smaller, this might be one explanation for one more significant correlation in the train group as compared with the group using all travel means.

For respondents with some sorts of functional limitations/diseases, the level of their functional ability was associated with how accessible they *perceived* the travel environment to be. Neurological diseases, chronic pain and restricted mobility had the highest correlation among the significant ones. Mild symptoms might not pose any problems in the travel environment although the same diagnosis or impairment might imply more severe symptoms leading to a more challenging travel environment. More seriously restricted mobility (that may be central in all of these three disorders; that is, neurological diseases, chronic pain and restricted mobility, might pose problems in the travel environment that other impairments, like hearing impairment, would not, in the same environment. It is thus important to focus on the most affected groups in order to find out more in detail what kinds of barriers they encounter and what can be done to increase accessibility for them. Notably, few of our respondents reported that they were low in functional ability. This is a source of uncertainty in our data. Another source of uncertainty is that some of the functional limitations/diseases were represented only in a few respondents. For example, only four persons with epilepsy had scaled their overall accessibility, whereas the group with restricted mobility were as large as 74. Moreover, even if there is no direct link between functional ability and overall accessibility for some of the functional-limitation groups, it does not necessarily mean that the respondents do not experience barriers. Even persons without functional limitations experience certain barriers. For example during delays, passengers might be equally disturbed, independent of functional ability

Pricing was seen as the most important barrier for not travelling more often, indicating a variable central to accessibility. On the other hand, pricing did not correlate with overall accessibility. A possible reason could be that it is not regarded as an accessibility issue. It could be that accessibility is more often regarded as a matter of, for instance, the physical environment, information and/or time keeping.

More than 40% of the respondents said they would like to travel by train more often, so there seems to be an unmet need. The overall goal of this paper was to facilitate the development of a public transport system that can better meet the specific needs of groups that are often neglected. This explorative research adds to the previous knowledge of elder persons' perception and needs in the public transport system in proposing a prototypical measuring instrument (questionnaire) that builds on a theoretical model for how accessibility may be explained. The constructs functional limitation, railway accessibility, functional ability, barriers, travel behavior were found to be a useful basis for measuring accessibility in the travel environment.

In a large Swedish survey, in year 2006, the response rate for ages 45-74 years was 63% while it was 50% for ages 75-84 years. Besides higher rates of diseases and functional limitations with increasing age, fall-outs might be expected because older persons would tend to consider their travel habits unimportant. Moreover, as for the general population, active persons tend to participate more frequently in questionnaire studies, and, consequently, the representativeness of the results might be lowered (Linder, 2007). In fact, many of those who contacted us because they did *not* want to participate, specified their reason to be "not travelling by train".

Another limitation is the cross-sectional nature of the research study. Therefore, causal inferences are not possible to make and no test-retest could be conducted. In this paper, we study travel behavior in relation to frequency of travelling, travel mode and destination. There are many other **important factors** in travel behavior, which we have not studied here, for example affective components (Olsson et al, 2012).

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Appendix 1

If it becomes less expensive to travel	62 %
If departure and arrival times are kept	49%
If I know I will be in time at the final destination	48 %
If I know I will be in time for my connection	47 %
If do not have to change means of travel during the trip	43 %
If I know I will get help if I need	42 %
If it is not crowded onboard	40 %
If I know I will be in time for the long-distance train	33 %
If the travel time will be shorter	33 %
If it becomes easier to find an empty seat	33 %
If it becomes easier to book/purchase tickets for the whole journey at the same time (even connections)	33 %
If there is service staff at the platform	29 %
If I can feel secure going to and from the station	26 %
If the attitude of the staff becomes more service minded	26 %
If I am not afraid of being harassed	25 %
If I can be sure I will manage the whole journey	25 %
If it becomes easier to get help from staff onboard	25 %
If it becomes easier to book/purchase tickets	24 %
If the environment becomes less busy	24 %
If i get more time to get on or off the train	24 %
If the departures become more frequent	22 %
If it becomes easier to get help from staff within the station area	22 %
If I become healthier and therefore can manage to travel	20 %
If the staff becomes more proficient	20 %
If it becomes easier to park at the station	19 %
If I do no need to keep track of so many things during the trip	18 %
If trains and stations are designed in a more homogenous way	15 %
If it is possible to travel att other hours (for example at night)	11%
If other passengers' attitudes become better	11 %
If I do not have to travel under ground	9 %

Appendix 2

	At least occasionally
Car	93%
Local bus	87%
Subway	87%
Airplane	66%
Commuter train	59%
Local train	54%

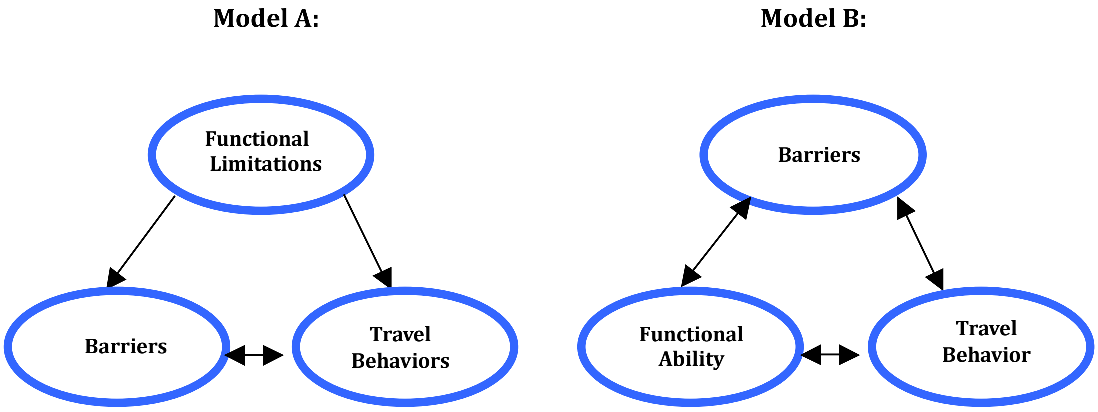

Figure 1. Overall accessibility models for travelers with various kinds of functional limitations (Model A) and for various kinds of barriers appearing as person-environment interactions during trips (Model B).

Table 1
Demographic characteristics of the random sample of respondents 65-85 years in Stockholm county (N=574)*.

Descriptive	All n (%)	Not reduced functional ability n (%)	Somewhat reduced functional ability n (%)	Very reduced functional ability n (%)	Cramér's V (p)
Gender:					0.11 (0.026)
Women	312 (54)	177 (58)	109 (36)	21 (7)	
Men	262 (46)	141 (56)	106 (42)	6 (2)	
Age:					0.14 (0.004)
=< 72	314 (55)	192 (63)	104 (34)	10 (3)	
=>73	257 (45)	124 (49)	110 (44)	17 (7)	
Retired	568 (95)	295 (56)	206 (39)	26 (5)	0.06 (0.321)
Income/month(SEK):					0.17 (0.000)
0-16 499	148 (27)	62 (43)	71 (49)	12 (8)	
16 500-33 499	228 (42)	121 (54)	89 (40)	12 (5)	
33 500-50 000	165 (30)	116 (71)	47 (29)	1 (1)	
50 000<					
Family:					0.09 (0.107)
Living with family/in nursing home	390 (68)	229 (60)	135 (35)	17 (4)	
Living alone	181 (32)	89 (51)	77 (44)	10 (6)	
Car in household	408 (71)	240 (60)	148 (37)	11 (3)	0.17 (0.000)
Driver's licence	458 (80)	262 (58)	174 (39)	13 (3)	0.18 (0.000)
Discount card	439 (77)	266 (62)	158 (37)	6 (1)	0.23 (0.000)
Mobility service	43 (8)	5 (12)	22 (52)	15 (36)	0.33 (0.000)

*N = total number of respondents; n = subsamples of respondents.

Table 2
Principal Components Analysis of Functional Limitations/diseases.

Functional Limitations/Disease	PCA Component[1]
Functional Limitations	
Attention, memory, concentration disability	C1 (.827)
Reading, writing or speech disability	C1 (.720)
Mental ill-health	C1 (.545)
Chronic pain	C2 (.789)
Restricted mobility	C2 (.741)
Hearing impairment	C3 (.778)
Vision impairment	C3 (.731)
Diseases	
Chest disease	C4 (.676)
Cardiovascular disease	C4 (.605)
Asthma, allergy, hypersensitivity	C4 (.591), C5 (406)
Epilepsy	C5 (.801)
Neurological disorder	C2 (.338), C5 (.514)
Rheumatic disease	C6 (.769)
Diabetes	C3 (.402), C6 (.547)
Travel sickness	C7 (.547)

[1] C 1-C 7 refer to extracted components in a 7-component analysis.

Table 3
Reduction in functional ability as a function of sort of functional limitation/disease.

Functional limitation/ Disease	None [2](a) n (%)	Somewhat (b), (c) n (%)	Very (d), (e) n (%)	N n (%)	Cramer's V [3] Value (p)
Restricted mobility	7 (9)	56 (69)	18 (22)	81	0.46 (0.000)
Chronic pain	8 (14)	35 (64)	12 (22)	55	0.34 (0.000)
Reading, writing or speech disability	0 (0)	6 (50)	6 (50)	12	0.32 (0.000)
Attention, memory, con-centration disability	4 (17)	13 (56)	6 (26)	23	0.24 (0.000)
Chest disease	4 (16)	16 (64)	5 (20)	25	0.21 (0.000)
Rheumatic disease	5 (19)	16 (62)	5 (19)	26	0.20 (0.000)
Cardiovascular disease	34 (35)	56 (58)	6 (6)	96	0.20 (0.000)
Hearing impairment	47 (40)	63 (53)	9 (8)	119	0.18 (0.000)
Vision impairment	49 (40)	62 (51)	10 (8)	121	0.17 (0.000)
Mental ill-health	4 (24)	11 (65)	2 (12)	17	0.12 (0.017)
Neurological disorder	3 (25)	8 (67)	1 (8)	12	0.09 (0.086)
Diabetes	29 (48)	26 (43)	6 (19)	61	0.09 (0.095)
Asthma, allergy, hyper-sensitivity	29 (45)	31 (48)	4 (6)	64	0.08 (0.164)
Epilepsy	2 (40)	2 (40)	1 (20)	5	0.07 (0.270)
Travel sickness	11 (58)	8 (42)	0 (0)	19	0.04 (0.600)

Table 4
Reduction in functional ability as a function of number of functional limitations/diseases (N=555, Cramer's V 0.429, p 0.000)

Number of functional limitations/diseases	None n (%)	Somewhat n (%)	Very n (%)
0	149 (81)	33 (18)	2 (1)
1	111 (62)	64 (36)	4 (2)
2	38 (38)	58 (58)	4 (4)
3	12 (24)	31 (63)	6 (12)
4	2 (10)	16 (80)	2 (10)
5	1 (7)	10 (67)	4 (27)
6-8	0 (0)	3 (60)	5 (62)

[2] Response categories for functional ability: (a) not reduced, (b) somewhat reduced, (c) reduced, (d) very reduced, (e) extremely reduced.
[3] Cramér's V based on the three collapsed categories of functional ability.

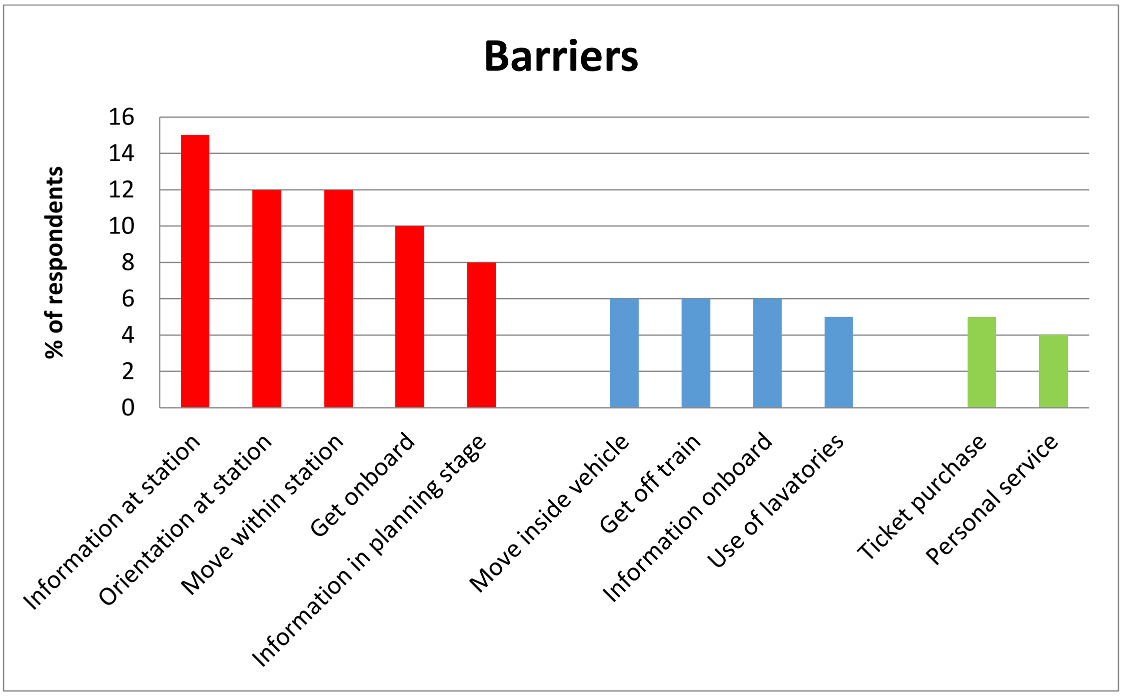

Figure 2. Barriers in long-distance train travelling experienced by respondents who travelled by long-distance train last year (N=145).

Figure 3
Perceived accessibility as a function of functional ability.

Table 5

Spearman correlations between functional and railway accessibility

Functional Limitation/ disease	Correlation	N
Travel sickness	0.34	16
Restricted mobility	0.32**	74
Vision impairment	0.20*	115
Hearing impairment	0.07	113
Reading, writing or speech disability	0.17	11
Attention, memory or concentration disability	0.17	20
Chronic pain	0.38**	51
Asthma, allergy, hyper-sensitivity	0.06	60
Mental ill-health	0.19	17
Cardiovascular disease	0.15	90
Chest disease	0.24	23
Epilepsy	0.40	4
Neurological disorder	0.85**	12
Rheumatic disease	0.11	24
Diabetes	0.28*	57

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 6. Mean travel frequency (95% CI) as days per month travelled with trains combined as a function of perceived railway accessibility.

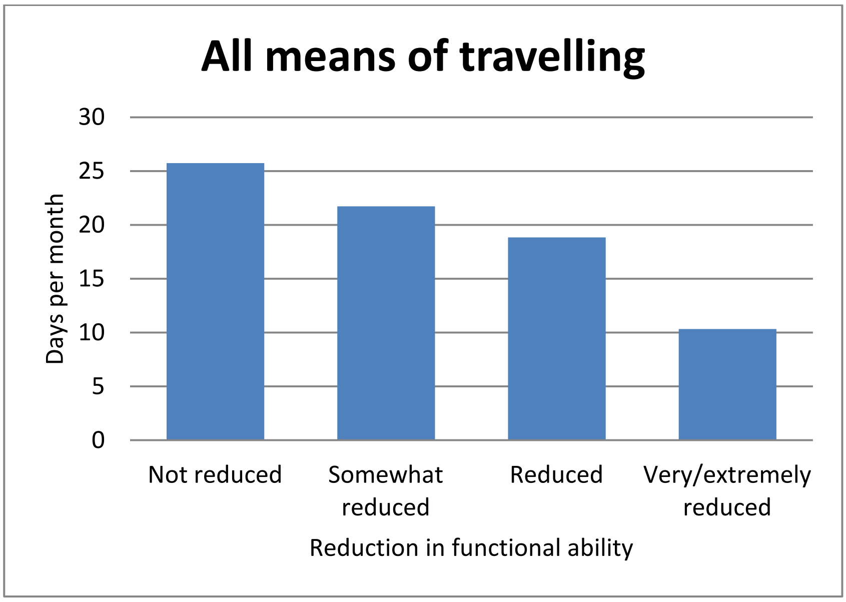

Figure 5. Mean travel frequency as days per month travelled with all travel means combined as a function of functional ability

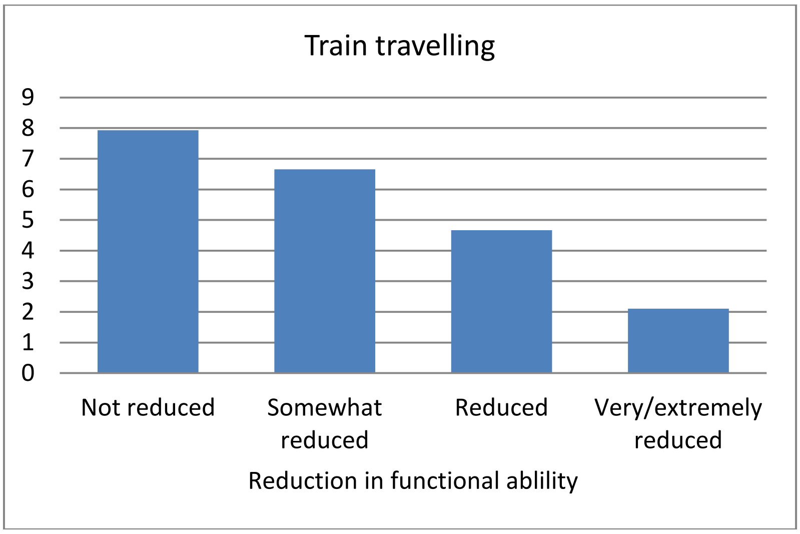

Figure 6. Mean travel frequency as days per month travelled with trains combined (long-distance train, commuter train, underground and local train), as a function of functional ability

APPENDIX II

Critical incidents in train travelling and their effects on travel behavior for older persons with functional limitations, Sundling, C., M. Nilsson, B. Berglund, S. Hellqvist, R. Emardson, L. Pendrill, to be submitted to Journal of Service Research.

Critical incidents in train travelling and their effects on travel behaviour for older persons with functional limitations.

Catherine Sundling (a)

Mats E. Nilsson (b)

Birgitta Berglund (c)

Sara Hellqvist (d)

Leslie Pendrill (e)

Ragne Emardson (f)

(a) Ph D, Stockholm University, Department of Psychology, SE-106 91 Stockholm, Sweden, tel: +468164601, fax: +468159342 catherine.sundling@psychology.su.se

(b) Professor, Institute of Environmental Medicine, Karolinska Institutet, P.O. Box 210, SE-171 77 Stockholm, Sweden, and Stockholm University, Department of Psychology, SE-106 91 Stockholm, Sweden, tel: +468164605, fax +468159342 mnn@psychology.su.se

(c) Professor, Institute of Environmental Medicine, Karolinska Institutet, P.O. Box 210, SE-171 77 Stockholm, Sweden and Stockholm University, Department of Psychology, SE-106 91 Stockholm, Sweden, tel: +468163857, fax: +468161002 birgitta.berglund@ki.se

(d) Research Assistant, Stockholm University, Department of Psychology, SE-106 91 Stockholm, Sweden, tel: +468163853, fax: +468159342, sara.hellqvist@psychology.su.se

(e) Professor, SP–Technical Research Institute of Sweden, P.O. Box 857, SE-501 15 Borås, Sweden, tel: +46105165444, fax: +46105165620

leslie.pendrill@sp.se

(f) Ph D, SP–Technical Research Institute of Sweden, P.O. Box 857, SE-501 15 Borås, Sweden, tel: +46105165727, fax: +463313 55 02

ragne.emardson@.sp.se

Key words: Critical incidents' technique; functional limitation; older persons; public transport; train travels.

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Abstract

The train-travel behaviour of older persons with functional limitations can be affected by cognitive, emotional and behavioural responses to particular travel incidents. With the objective of identifying such incidents and examining how travel behaviour is changed, we have used the critical incidents method, collecting 470 incidents in public transport travelling, through interviewing 30 elderly participants with some kind of functional limitation. 78 of the incidents were found to highly influence travel behaviour negatively. Reactions leading to changed travel behaviour typically referred to five themes; actual limitations, dynamic factors, unfair treatment, complicated travels and associated earlier experiences. More personal assistance would improve predictability in the travel environment and facilitate travels for many older persons. Moreover, including different groups of end users in planning and design, would allow for more tailor-made travel environments.

1. INTRODUCTION

An accessible public transport is a governmental issue. In 2000, the Swedish government's action plan presented the goal of a completely accessible transport system throughout the country by 2010 (Banverket, 2005). It is well known that mobility, including accessible public transport, contributes to a better quality of life for many older persons. Transportation is important for example in order to visit family and friends, for shopping, physical exercise and sport (Linder 2007). Many older persons would like to engage in activities more often but as many of them have various functional limitations, barriers or incidents encountered in the travel environment are one of the main obstacles. (Gabriel and Bowling 2004, Farquhar 1995, Su and Bell 2009).

Regardless of whether these incidents appear in the physical environment, in information or elsewhere in the travel environment, some of them make travelling difficult or impossible. Exactly in what way different incidents are experienced and how they are linked to future travel behaviour for the individual is not always evident. Little research has been conducted on the passengers' interactions with the public transport service (Friman, Edvardsson and Gärling 2001). Especially little is known about older persons' travel behaviour and needs but as every fifth person in the world will be 65 or older in four decades from now, it becomes increasingly important that transport systems are built to meet the special needs of this group (Statistics Sweden 2012).

The objectives of the present study were to:

- Explore, through interviews, what critical incidents have been encountered in public transport, by a sample of older persons with functional limitations or reduced functional ability. The trips have been made, at least in part, by train.
- Develop a classification scheme for better understanding of critical incidents encountered.
- Identify which of the critical incidents have resulted in changed travel behaviour and to assess how critical reactions (cognitions, emotions and behaviour) contribute in the process.

Different kinds of functional limitations lead to different problems in the transport environment. Persons with cognitive impairments, for instance, as a result of stroke, dementia and traumatic brain injuries, often face specific accessibility problems in terms of difficulties in coping in a constantly changing travel environment. This can reduce travel confidence and lead to decreased mobility. Also the severity of the same functional limitation as well as other factors such as earlier experiences and personality influence the interpretation of the travel situation. Therefore, a focus on the individual can reveal needs that would be hidden in the wider population.

In the present research, the traveler is not seen a passive respondent to the environment, but as an active agent, using resources in the travel environment and interacting with it (Bandura 2001, Pareigis, Echeverri and Edvardsson 2012). In service research, consumers are often viewed as “coproducers” in the service environment, involved in the creation of value. In order to develop services that match consumers’ needs, service providers therefore must involve consumers and view them as resources rather than “targets” (Vargo and Lusch 2004). The emotional response to a service has been found to be important in determining how it is perceived and future behavior is affected. Also, in order to understand how outcomes will affect behavior, cognitive factors need to be understood (Bandura 1978). Therefore, a service should then be designed with due consideration of function, cognition and emotion (Edvardsson, Enquist and Johnston 2010, Pullman and Gross 2004).

The present research is focused on railway travelling. As accessibility in train travelling is dependent on the whole trip chain from the planning stage until reaching the final destination, we also include ticketing, the way to and from stations and connections with other transport means.

2. METHOD

2.1 Critical Incidents’ Technique

The critical incidents’ technique (CIT) is explorative and is therefore useful when there is a lack of knowledge in the research area. It may contribute to the provision of groundwork for theory development. It has often been used in order to measure the performance of a system from a consumer’s perspective. A critical incident is an event that is particularly satisfying or dissatisfying. CIT typically uses content analysis of stories, rather than quantitative methods in the data analysis (Bitner, Booms and Tetreault 1990, Gremler 2004). In content analysis, the participants’ stories are treated as reports of facts. When using CIT, a situation is concretized in order to be more clearly described. The reason for choosing the CIT in this study is that it may capture a broad spectrum of experiences without pushing participants in a certain direction. It also facilitates an insight into the participants' decision process because it uses their actual experiences. (Edvardsson 1998).

2.2 Sample and procedure

Generally, a critical incident could refer to either a chain of events (in this case during a whole journey, from the planning stage until reaching the final destination) or each event could be seen as a separate incident. In the present study, each event is seen as a separate incident. When several incidents occur during the same trip, each incident has been analysed separately, but with allowance for a preceding incident acting as an antecedent that possibly influences perception of subsequent incidents.

Criteria for including a critical incident were:

- An occurrence that affected (positively or negatively) the experience of a journey.
- It was experienced by the interviewee.
- It occurred during the last 2 years in Sweden.
- The journey was (at least in part) made by train (all rail-bound means).
- The whole journey is included, meaning that the incident could have happened anytime during the journey, from the planning stage until reaching the destination.

After approval from a local ethical committee, data was collected in the form of individual post trip interviews. Additionally, a questionnaire was used to collect background data. One of the authors served as the interviewer. Using only one interviewer can be an advantage in terms of avoiding inter-interviewer bias and selectivity in listening and recording (Keaveney 1995). The interviews were held in the participants' home or at the university, depending on the participant's wish. One interview was conducted at the participant's workplace.

The participants were 65-92 years old (mean 76) and living in the county of Stockholm, Sweden. All except one had travelled by train (all rail-bound means) during the last two years (see above, under inclusion criteria). One participant had not travelled by train the last two years because of inaccessibility. She was included because we found her experiences of value for the research purpose. This participant's answers are presented, not as incidents, because they fell outside of the inclusion criteria, but as examples of exclusion from traveling by train. It can be considered as a special case where inaccessibility for this individual affected the experience of a journey so strongly that travel was not even undertaken. The reason for limiting experiences to the last two years was ensure that the system would not have changed substantially and facilitate recollection.

All participants had some kind of functional limitation, most frequently restricted mobility and vision impairment. Because of the age group, most of the interviewees had a combination of different deficits. Around half of the participants were recruited from an earlier research study we had performed with the aim of exploring connections among functional ability, barriers encountered in the transport system, and travel behaviour, for older persons with and without functional limitations. Remaining participants were recruited by advertisement in a local paper, through the municipality's care for the elderly and by the snowball method (participants referring each other), giving a total of 30 participants, 24 women and 6 men.

Prior to each interview, the goal was stated and questions of anonymity and free consent were addressed. The participant was given the following instruction: *Think of an incident or event that affected your experience of a journey in a negative or positive way. Think of the whole trip, from the planning stage including ticketing, all the way until reaching the final destination. Think of a trip in which you travelled by train (all rail-bound means) at least as a part of the journey. Choose an incident that you remember well and if you remember several, start with the one that feels most important.*

The respondents were allowed to give information on an unlimited number of incidents and the interview continued until the incidents remembered were exhausted. Both *occasional* and *repeated* incidents were collected (Edvardsson 2001, Friman and Gärling 2001). The interviewee was asked to give a detailed description of each incident, including antecedents, and cognitive, emotional and behavioural reactions to the incident (Butterfield et al. 2005). The interviewer posed open questions about the antecedents, course of the incident and responses. *Antecedents* referred to long term and short term occurrences and expectations preceding the incident, both in the environment and within the person (e g cognitions, emotions and behaviour). The *responses* referred to the person's long term and short term cognitions, emotions and behaviours following the incident. The answers were written down directly and interviews were recorded to ensure descriptive validity (Butterfield *et al*. 2005, Maxwell 1992).

The respondents rated each incident according to how strongly it had influenced travel behaviour, choosing between the alternatives “1; no influence”, “2; low influence” or “3; high influence”. A high negative influence on travel behaviour meant that travel behaviour had actually been changed because of the incident; for example ceasing to travel alone; reducing the number of trips considerably; or ceasing to travel altogether with the travel mode in question. But it could also include lesser changes; needing to plan a trip more thoroughly or to use new kinds of luggage. In any case, the respondent judged the incident as having changed the way of travelling significantly. A high positive influence implied more frequent travelling than without the incident.

In CIT, the sample size is typically determined, not by the number of participants, but by the number of usable critical incidents, the unit of analysis. Data collection is completed when there is a sufficient degree of saturation and stability in the data, (Edvardsson 1992, Flanagan 1954). In the present research, after 15 interviews were conducted, no additional incidents lead to additional categories (Butterfield et al. 2005). Because of the heterogeneous group including different sorts of functional limitations and additionally heterogeneity in the travel means, we chose to make another 15 interviews, in order to ensure a sufficient spread in the incidents collected. Because of the heterogeneous group, perceptions of what constitutes an incident in the same environment are often diverse and therefore an individual approach must be adopted. A total of 470 usable incidents were collected, 380 negative, 84 positive and 6 both positive and negative. Usable incidents were those which met all inclusion criteria listed above.

2.3 Classification of incidents

The next step in the process was to analyse the data. Two researchers, both trained psychologists and authors of the present study, independently extracted critical incidents from the interviews and categorised them (Butterfield *et al.* 2005). First, when 10 interviews had been conducted, one of the researchers (the interviewer) listened to the recorded interviews, made completing notes and started categorising the incidents according to similarities in one of the dimensions (Interaction with Travel Environment dimension, relating to “Place”) (Bitner, Booms, and Stanfield Tetreault 1990). After another 10 interviews, it was decided that this categorisation should be used continuously and that another dimension (Travel Chain Dimension, relating to “Time”) should be added, see Figure 1. Thus, when all interviews were completed, the researcher sorted each incident into one of the categories in each dimension by repeated listening and taking notes. The groups in each dimension were thus exhaustive.

The Travel Environment Dimension regards aspects *encountered,* such as: the physical environment; pricing; staff; information; time and connections; fellow passengers; and flexibility of transport system. The Travel Chain Dimension refers to: ticketing and planning; going to the station of departure and from the station of final destination; being at the station; getting on and off the vehicle; being inside the vehicle; as well as incidents applying to more than one of these travel chain incidents. The categorisation was made in accordance with what was believed to be the most valuable way of communicating needs for change in the transport system (Flanagan 1954).

Next, a categorisation scheme with definitions and instructions was created (see Appendix A) and the second researcher, after being introduced to the categorisation scheme, independently categorised one interview as a test interview. Differences in categorisation were discussed until consensus was reached. After that, the second researcher sorted the rest of the material into the categories. She decided what should be regarded as incidents according to the inclusion criteria and then sorted the incidents into the different categories in the two dimensions (Environment and Chain). The inclusion and categorization of incidents were then compared between the two judges and disagreements were discussed until consensus was reached for the whole material.

Insert Figure 1 about here

2.4 Interjudge reliability

After the test interview, the coefficient of agreement (total number of agreements divided by total number of coding decisions) was 80%, increasing to 82% when all interviews had been conducted. Interjudge reliability was then assessed using Perreault's and Leigh's Ir statistic (Perreault and Leigh 1989, Gremler 2004). This reliability index also takes into account the number of categories. Interjudge reliabilities exceeding .80 are considered satisfactory (Keaveney 1995, Kassarjian 1977). In this case interjudge reliability was 0.90 for the Travel Environment Dimension and 0.88 for the Travel Chain Dimension. Differences in categorisation were discussed until consensus was achieved. All incidents sorted into one category of each dimension, resulted in 31 combinations of dimensions, making up a new set of combined categories.

3 RESULTS

3.1 Categories of incidents encountered

Typically, the primary results of CIT studies are the categories that emerge (Bitner, Booms & Stanfield Tetreault 1990). In this section, we will first present an overview of these categories for the two dimensions (Environment and Chain) followed by the combination of them. This is done in order to describe and map the *range* of incidents encountered. Second, we will focus the presentation on the *most important* incidents; those leading to atangible impact on travel behaviour, either positively or negatively. Third, we will focus on the travellers' cognitive, affective and behavioural *reactions* to the most important incidents, in order to explore why the incidents were experienced as important for the travellers. Here, we also take into consideration how incidents may function as antecedents for other incidents and thus impact the perception of the latter. For example, if a traveller has already encountered one barrier, the next barrier may be perceived as more troublesome than if it had been the first one to encounter (Gremler 2004).

The incidents are classified according to respondents' attributions (Edvardsson 1998). For example, if a respondent has encountered difficulties regarding luggage inside a vehicle, the incident has been coded as "staff" if the respondent is arguing that lack of staff is the reason for the problem, but is coded as "physical environment" if it is attributed to the design of the vehicle. Additionally, the same event is sometimes coded as more than one incident. For example waiting for the bus in a poorly lit bus station (physical environment) and at the same time feeling unsafe because of the people there (fellow passengers) is coded as two incidents depending on the two attributions, both referring to the "station" part of the trip chain.

3.2 Incident Classification System – Travel Environment "Place" Dimension

Pricing and planning: Respondents' perception of price level and tariff structure that affect the costs. For example tickets being perceived as expensive or inexpensive or tariff structure difficult to understand.

System Flexibility: How special needs or requests are met by the transport system. For example the possibility of booking tickets without a computer; to be able to choose one's seat; or to bring a bicycle on the vehicles.

Physical Environment: The physical environment in each part of the travel chain. Examples include possibility to reach the station relying on snow clearance of pavements; the reliance on elevators and escalators in stations; and the importance of vehicle design for storage of luggage.

Information: The possibility and easiness to get information during the different parts of the travel chain.

Fellow Passengers: How other persons (except staff) act within the transport system. This category does thus not apply to "To and from the station" in dimension B.

Staff: Perception of staff, for example personal service, attitudes of staff, shortage of staff.

Time/Connections: Time aspects; waiting time, punctuality, time to change to connecting travel means.

3.3 Incident Classification system – Travel Chain "Time" Dimension

Ticketing. Incidents concerned with the ticket information or purchasing phase of the trip.

To and from station: Incidents on the way to and from the start or end destination station or stop areas (not when the respondent is changing between different public transport means).

At station: Inside the station area or bus stop area.

On and off vehicle: Getting on-board or off the vehicle.

On-board: The phase of the trip when being on-board.

More than one part of the trip: Incidents that concern more than one part of the travel chain.

3.4 Combined Categories

When all 470 incidents had been sorted into each of the two dimensions of categories, a total of 31 combined categories were then identified (i.e. as being common to both dimensions). The Travel Environment Dimension had 7 categories and the Travel Chain Dimension had 6 categories, thus theoretically giving a maximum of 42 combined categories. The incidents were, however not evenly distributed, so 11 combined categories were empty. For example, no participants mentioned incidents regarding the combination *Ticketing* and *Fellow Passengers* even though the combination would have been plausible. But some combinations were not mentioned because they were unlikely to emerge, e g getting *On or off the Vehicle* and *Pricing and Planning.* In Table 1, the categories are presented in order of the Travel Chain Dimension.

Insert Table 1 about here

As can be seen in Table 1, the most frequently mentioned incidents were found onboard vehicles and at stations/stops. Incidents in the physical environment were especially frequently mentioned, e g scarce space for walkers and luggage onboard vehicles or problems with elevators and escalators. Negative incidents were more frequently mentioned than positive; 81% of all incidents were negative. Earlier research suggests that negative incidents to a greater degree mobilize reactions than positive incidents do (Edvardsson 2001).

3.5 Critical incidents leading to changed travel behaviour

Although changing one’s travel behaviour may be a complex process and depend on more than a single event, some incidents certainly have more serious implications than others, in a negative or positive way (Edvardsson 2001). Hereafter we will focus on the incidents that highly influenced participants’ travel behaviour according to their own interpretation (reported as “high influence on travel behaviour” on the 3-grade scale during the interview). 78 or 17% of all critical incidents strongly influenced participants’ travel behaviour; 69 of them in a negative and nine in a positive way.

Table 2 shows how they are distributed across 21 combined categories. In many cases, alternative travel modes were a prerequisite for being able to change travel behavior. Some of the interviewees were discontent with the service but said they had no choice.

Insert Table 2 about here

As seen in Table 2, most critical incidents leading to changed travel behaviour were found in the physical environment, on-board the vehicle and at stations/stops, just as was the case with all incidents (Table 1). Again, incidents leading to changed travel behaviour often referred to problems with elevators, escalators and stairs that posed problems for persons with reduced mobility.

Another reason for changed travel behaviour was ticketing and pricing. It related to high prices but also satisfactory low prices in general or specifically low prices for retired or for traveling 1st class. Another complaint was non-transparent ticket prices that were difficult to understand or that sometimes only tickets bought over the internet could be bought for the lowest price.

3.6 Negative critical responses to incidents

Can it be explained, more in depth, why certain incidents have resulted in changed travel behavior? Sometimes a seemingly small incident may have severe consequences because of how it grows in the traveler’s interpretation and memory (Edvardsson and Roos 2001). Earlier experiences, for example negative publicity about punctuality before a trip is made, can be of importance for how an incident (e g delay) is perceived. Likewise, several incidents together, on the same trip, may have a cumulative effect. Therefore, studying incidents in the light of their antecedents and consequences, as a process and in context, can yield a better understanding than studying each incident in isolation (Edvardsson and Strandvik 2000, Gremler 2004, Butterfield et al. 2005).

Insert Figure 2 about here

Reactions in the form of emotions, cognition and short term behaviour can be regarded as mediating variables influencing long term travel behaviour. Five themes emerged in the travellers' reactions:

Actual limitations: Certain incidents that had been encountered constituted actual limitations, obstacles that were difficult or impossible to overcome. For example, the step was too high to climb, or the information was only given on the internet which the traveler did not have. Something was actually *not possible,* the person was being shut off from travelling all together or had to choose alternative ways of traveling. Further examples of this kind of problem were too expensive tickets or too little space between seats, causing pain in aching knees. Persons with walkers had difficulties getting to and from the stations in winter when the pavements were not cleared of snow. An actual limitation would invoke *resignation,* but the only immediate ways of dealing with the problem are either to find other ways of traveling or to stop traveling all together. For some respondents, traveling only in company had become a solution, leading to dependence, something that could be regarded as a barrier in itself. Having to adapt one's travels to other persons could also lead to isolation, resulting in a reduced travel frequency. In other cases, it had been possible to find other means of travel.

Dynamic factors: For many travelers, unpredictable events were a source of *insecurity*. Suddenly, the elevator is out of order or the bus driver stops far from the pavement making it difficult to get off the bus. Feelings of insecurity would also arise on the bus, when it was lurching and the interviewee was afraid to fall or when the bus driver started before the interviewee had found a seat. One person had fallen in such a situation and several others participants were afraid it would happen. Several interviewees had encountered problems with elevators or escalators being out of order. Sometimes this also resulted in worry before a trip. One interviewee had difficulties sleeping the night before a trip. The dynamic factors were described in different parts of the trip. One interviewee had sometimes been prohibited from making her trip because the designated accompanier from the municipality did not show up at her home when she was going to leave for the station. Another area of unpredictability was found in information. At the time of booking, it could be important to get information about the kind of carriage used, to avoid carriages with cramped space which might results in hurting knees, in the case of joint problems. Another example of the importance of information regarded getting correct information about what help could be expected on arrival. When a person was promised help from staff but did not get help at the destination, could result in ceasing to travel by oneself, thus becoming dependent on family members for traveling.

Unfair treatment: Some interviewees felt maltreated by the transport system. Fluctuating ticket prices; better prices online than on the telephone (when you do not have a computer) or long queues were examples of that. An interpretation of being treated disrespectfully or unfairly may create *anger* and *humiliation*. Some of the interviewees, who preferred fixed ticket prices, said knowing the tickets would be cheaper at other times made them feel fooled. One interviewee thought it felt like a penalty tax. Another participant compared first class double-decker trains with cattle-trucks, finding the carriages cramped and instable, and would never get on such a train again. Some of the interviewees did not have a computer or had difficulties using it and considered the system to be trying to force them into using a computer. Some regarded the transport system as an "enemy", not wanting to help, resulting in a weakened relation. Some also felt insulted by fellow passengers' mobile phone conversations. Finding oneself listening "almost compulsively" though not wanting to, could be regarded as unbearable.

Complicated travels: Encountering several barriers can together make the traveler reach a threshold above which it is no longer worth the *effort*. Again, fluctuating ticket prices were experienced as hard to grasp and made planning difficult. Having to put a lot of effort into finding and comparing prices was not worth the endeavor for some interviewees. Another example was connections that require coordination. Luggage must be carried between transport modes, the right bus stop must be found etc. Apart from the cognitive and physical load, the change of modes also created anxiety for not being able to manage all parts of the trip chain. Luggage was a source of discomfort for many interviewees, for example in combination with narrow spaces. Some interviewees found the luggage space too small, often resulting in lack of space for their bags. Therefore one of the interviewees had started using bags that were easier to pack, but that were less comfortable, for example a backpack instead of a carry-on case. Many interviewees would have preferred to have their luggage beside them, also to be able to keep an eye on it.

Associated earlier experiences: Antecedents or earlier adverse experiences in the transport system, e g having been hassled, followed or assaulted had created *vigilance* and reluctance to travel, especially at night, for some interviewees. Some would not travel alone; some women chose a carrier where there were other women and they wished for more guards at platforms and in trains. They also welcomed camera surveillance and staff overlooking the platforms and trains. Some of the interviewees preferred commuter trains to the underground because they could look out the window and felt less trapped inside if something would happen.

3.7 Positive Critical Reactions to Incidents

Just as *actual limitations* (e g expensive tickets) were reasons for not traveling, some had the opposite experience; e g inexpensive tickets were regarded as *actual possibilities* and constituted reasons for traveling more often. Also, what was experienced as *unfair treatment* or *complicated travels* by some, was regarded as an advantage by others. For example, fluctuating prices, that for some were regarded negatively, was also appreciated by some of the interviewees because it made it possible to buy inexpensive tickets if they were booked well in advance or at the last minute. Other positive incidents that constituted an opposite of complicated travels were (i) flexibility of ticketing (possibility of credit card payment on the phone) that made it easier to travel and (ii) frequent departures in the underground that additionally was experienced as a security factor. An example of a specific positive *associated earlier experiences* was when a traveler knew that there would be staff to help out with luggage at a particular station, which made traveling possible.

3.8 Serious events other than incidents

Some events fell outside the inclusion criteria for an incident, but should nevertheless be mentioned, because the severity of the event was the reason for not being able to make the journey at all. To be included as an incident, it had to take place during a trip and, therefore, reasons prohibiting a person from making the trip were not regarded as incidents.

- One of the respondents had not been able to travel by train at all during the last two years because of inaccessibility. Her answers are presented here together with other respondents'.
- Sometimes events during the ticketing phase had made the respondent choose another way of traveling, for example waiting times, expensive tickets or closed ticket office.
- Some events had happened several years ago, but had stayed in memory and made the respondent stop using train. Typically, it was the combination of barriers that made traveling impossible.
- For one respondent with heart disease, the combination of not being able to send her luggage when traveling by long-distance train (as in air travel), climbing the stairs into the train and having to change trains during the trip, had made her start flying instead of going by train as she did before.
- One respondent no longer traveled by train during winter, because of earlier experience of delays. She would not risk being trapped in a cold carriage somewhere between stations. Some respondents could travel by underground but avoided bus. A reason mentioned was that it would require a lot of courage to ask the bus driver to use the ramp in rush hour. For other respondents, it was the other way around: they would travel by bus but not by underground, mostly because of the necessity of using an elevator or escalator to reach the vehicle.

4. DISCUSSION

A total of 470 critical incidents were identified. In the classification scheme, some categories were found to predominate over others. The most frequently mentioned incidents regarded physical environment at stations and on-board the vehicle. These incidents were also those most often leading to changed travel behaviour. Moreover, it was possible to identify why certain incidents resulted in changed travel behaviour by assessing how cognitions, emotions and behaviour contribute in the process. 78 of the incidents had resulted in changed travel behaviour. Just as for the incidents in general, those resulting in changed travel behaviour were also most frequently found in the physical environment; at stations; and on-board the vehicle. Cognitive, emotional and behavioural reactions formed five groups of negative critical reactions leading to changed travel behaviour; actual limitations, dynamic factors, unfair treatment, complicated travels and associated earlier experiences.

The research study identifies specific events and their subsequent cognitions, emotions and behaviours that resulted in changed travel behaviour for our group of older persons with functional limitations. It is important to identify critical points wherever they occur in the travel chain. Using the CIT helps finding these points without any preconditions. Most transport research is focused on “mainstream” travellers, with individuals seen as interchangeable. But for persons with functional limitations and for older persons, the perceived barriers to travelling may vary depending on individual characteristics. Therefore, it is important to develop ways of measuring accessibility from an individual perspective and to include persons with various prerequisites in the encounter with the transport system. Presently, there is a shortage of measuring instruments for these groups. Our study deepens the knowledge about the perceived accessibility in the public transport environment for these underrepresented groups of travellers in research.

In order to describe experiences of the public transport system from an individual perspective, the heterogeneity of our sample of older persons, gives a pattern of perceived difficulties in the transport environment that should work against serious biases in answers. They have been recruited in different ways, live in different municipalities and there are differences in age, gender, functional limitations, travel means etc.

Most incidents mentioned were negative. This may be a reflection of the interviewees’ experiences of public transport; negative critical incidents could have more impact than positive critical incidents due to loss aversion (Kahneman and Tversky 1979; Friman, Edvardsson, and Gärling 2001). The interviewees may also have been “directed” towards negative associations by the word “incidents” used as instruction during the interview.

Most incidents referred to the physical environment and at the station/stop or in the vehicle. A reason may be that it reflects the interviewees’ experiences. But some of them asked if they could include even the way to and from the station/stop, it was not evident for them although it had been said in the beginning of the interview. Therefore, those categories may be underrepresented together with other more peripheral categories relative to the train.

4.1 Implications for transport authorities

Many interviewees wished to have more *personal* assistance (staff). The present research indicates that predictability in the transport environment is an important feature for the group of older persons with functional limitations. Increasing predictability in the whole trip would increase the ability to travel for many older persons. Personal assistance was regarded as a more flexible and predictable solution than the many specialized electronic devices. An example of what was asked for was staff to help out with ticket purchases made on the internet at larger stations, when computers were difficult to understand. That way, it would be possible to learn more about the electronic system and to become more independent. At platforms, staff ideally should help out with issues ranging from assisting with luggage to information and security.

Unpredictability may create a feeling of helplessness, for example when the *information* given at ticket purchase is not correct. One passenger had not been informed that there would be a change of travel means because of track work and this created thoughts and worry of how to be able to bring her luggage between travel means; to find the right bus etc. Another passenger was told there would be staff to help her get off the train, but it turned out there was no one to help her when she arrived.

Absence of staff was a general complaint and many of the incidents constituting actual limitations, dynamic factors, unfair treatment, complicated travel and associated earlier experiences were attributed to too little personal assistance.

The present findings contribute to an increased knowledge of features in the public transport environment that can be experienced as insufficiencies in public transport by older persons. It also indicates why these features have been experienced as insufficiencies. Using the CIT has proved useful in providing detailed and in-depth descriptions of events critical for travel decisions. The identified events, cognitions, emotions and behaviours can be used as a base for designing service procedures and policies. CIT can identify how service can be improved by pointing out what travellers consider important in different parts of the travel chain (Bitner, Booms, and Stansfield Tetreault 1990).

Improvements that would enhance predictability in the travel environment are - apart from improved personal assistance - better driving behavior; supported way finding; and improved technical support at stations. Additionally, if different groups of end users were included in planning and design of travelling routes, it would be possible to design more tailor-made travel environments.

4.2 Strengths and limitations

The research study has been based on certain assumptions that should be pointed out. In content analysis, the stories told are not questioned or interpreted by the researcher, but taken as facts. The researcher regards the stories as the “truth” for the interviewee. The method thus gives “pure” data; the researcher asks for events that have actually happened to the participants, and a report of the event is given from the participants’ own point of view. There is also an emphasis on accuracy: what specific events lead to the incident and exactly what did the traveller do or say. Vague reports are excluded. The free responses are then placed in a measurable framework (Hopkinson and Hogarth-Scott 2001). But it has been assumed that the respondents have given truthful reports on experiences as is usual in interview studies. Naturally, we do not know anything about how truthful the responses are. In addition, asking about past events always means exposure to biases in memory and this may be especially true for older persons. This may be a disadvantage of CIT and other retrospective self-reports relying on memory, in that responses may be biased due to distortions (Kahneman 2000). On the other hand, as the travellers are making their own travel decisions for the future, it may be of less importance what really happened. The lingering effect is often the most important factor for future travel behaviour.

It is assumed that public transport accessibility could be captured and described by 31 categories. This is one way of categorizing incidents: other ways might have been equally relevant. In any case, they would have yielded different results. The way of categorization directs the results (Johnston 1995). On the other hand, the core content should probably be the same (Edvardsson 1992). Additionally, 31 categories is an unusually large number in this kind of research. It has the advantage of segregating the result in order to yield more precision, but it has not been possible to give an exhaustive exposition of all categories.

4.3 Implications for future research

In the present research, data has been collected for theory-building. It is an empirical starting point for generating new research evidence (Kolbe and Burnett 1991). The categorisation system that emerged from the data and that identifies sources of inaccessibility can be used to find areas of importance for further investigation. It could be applied also to other groups of travellers in future public transport research. Having defined important incidents in the transport environment for our group of older persons, the results may be used to improve measurements in transport accessibility for the individual traveller as well as at group level. The severity or weight of specific incidents for an individual may be measured, depending on how much effort is needed to overcome the incident and how probable it is to encounter that specific incident on a specific trip (Sundling *et al.* 2011). That way, measurement of accessibility in the public transport system may be further improved.

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TABLE 1
Critical incidents in categories presented in order of Travel chain.

Categories. Number of incidents (neg/pos	*Sample incidents, negative*	*Sample incidents, positive*

Ticketing (Sum 57)		
x Pricing (15, 10)	Must make bookings on computer to get the lowest price.	Inexpensive 1 class tickets for senior citizens.
x System Flexibility (11, 2)	Could not order mobility assistance by telephone, only on the internet, which I did not have.	Possible to use credit card at telephone bookings.
x Phys Environment (1,0)	They are placing passengers beside me though the rest of the carriage is empty.	-
x Information (9, 2)	Do not know what kind of carriage at booking, if enough space between seats, otherwise, knees will hurt.	The journey planner (on the internet) is a good help.
x Staff (0, 1)		Good ticketing service at stations.
x Time and Connections (6, 0)	Long queue for booking. Missed the train.	-
To and from Station (Sum 17)		
x Pricing (2, 0)	Expensive parking near station.	-
x Phys Environm (12, 1)	Slippery pavement. A man helped me. The next time I travelled another way.	Dropped kerbs.
x Time and Conn (2, 0)	Short intervals for crossing the street to the bus stop. Not enough time to reach the other side.	-
At Station (Sum 124)		
x Pricing (0, 2)	-	Was given a check for coffee and a paper because of delay.
x System Flexibility (1, 0)	To report (by telephone) an escalator that is out of order, they need the number, not just the position.	-
x Phys Environment (62, 4)	Escalators vertiginously long and fast moving.	Clean and well-kept stations.
x Information (18, 3, 1 both neg and pos)	Not possible to hear loudspeaker announcements.	Digital displays are good. You can see when the next train will arrive.
x Fellow Passengers (3, 0)	Do not want to travel late because of some of the persons at the station.	-
x Staff (17, 5)	Unmanned station area makes you dependent on fellow passengers for help.	The ticket collector helped me through the station all the way to the train.

x Time and Connections (8, 0)	Not possible to get on train until 5 min before departure. Difficult to stand on platform and then do not have time to sit down inside train before it start moving.	-
On and off Vehicle (Sum 41)		
x Physical Environment (17, 0)	Narrow and steep when getting on and off train.	-
x Fellow Passengers (3, 2)	Difficult to hold on to the door-frame when getting of train when people are squeezing themselves out.	Fellow passengers helped me with walker and bags.
x Staff (19, 0)	The bus stopped far from the pavement. Almost had to jump. Thought I would fall.	-
Onboard (Sum 147)		
x Pricing (2, 2)	The food is expensive.	Get free coffee because of member card (Priokort)
x System Flexibility (1, 1)	Not possible to bring the bike on the train.	Even if there are many passengers, you always have your seat (at long-distance trains).
x Phys Environment (58, 10)	Impossible to keep watch over my luggage inside the carriage.	In a commuter train, you are travelling above ground. They have nice interiors and are easier to get out if something would happen (compared to underground).
x Information (9, 2)	Handicap sign missing, therefore seat taken. Do not want to ask someone to stand up for me.	When train stopped in tunnel, we got continuous information.
x Fellow Passengers (29, 3, both pos and neg 2)	People are talking in their mobile phones. Unbearable!	Young people stand up to let me have their seat.
x Staff (18, 8)	Could not lift the bag onto the luggage rack. No staff present.	Driver drove smoothly and considerately.
x Time and connections (2, 0)	Delay.	-
More than 1 part of Trip (Sum 84)		
x System Flexibility (7, 2)	Difficult to express one’s view, have to do it in writing. Difficult when I don’t have a computer.	Extended route network; possible to travel wherever I like.
x Phys Environment (7, 1)	Too crowded in the travel environment. May be pushed by mistake.	Comfortable to travel by train.

x Information (9, 0)	Carriers signposted with wrong numbers. When already having got on-board the signs were changed.	-
x Fellow Passengers (8, 5, both pos and neg 2)	Intrusive beggars.	Kind, polite and helpful passengers.
x Staff (7, 8)	Lack of staff or guards on platforms and in underground trains.	Kind and service-minded staff.
x Time and Connections (17, 10, both pos and neg 1)	Difficult to change travel means especially with luggage. To find the right platform or bus stop.	The underground is fast, accessible and punctual.
Sum Total **470**		

TABLE 2
Critical incidents' with *high influence* on travel behaviour in categories presented in order of travel chain.

Categories, Number of High Influence Incidents (neg, pos)	*Sample incidents, negative (-), positive (+)*
Ticketing (Sum 17)	
x Pricing (7, 2)	Prices vary depending on time for booking. Feeling decieved. (-) Inexpensive tickets. (+)
x System Flexibility (2, 1)	Was supposed to buy tickets on the internet to get updated information, best price, to choose my seat. Everyone do not have internet. (-) Can pay with credit card on the phone. (+)
x Information (4, 0)	Did not know that the train would be replaced by bus part of the distance. If I had known, I would not have booked. (-)
x Time and Connections (1, 0)	Long waiting time for booking at station. (-)
To and from Station (Sum 3)	
x Pricing (1, 0)	Expensive parking at daytime. Try to travel in other ways. (-)
x Phys Environment (2, 0)	Pavements not snow swept or sanded. (-)
At Station (Sum 18)	
x Phys Environment (12, 0)	The elevator out of order. Cannot travel by underground, what if the elevator is out of order again? (-)
x Information (1, 0)	Difficult to find your way, poor signposting. (-)
x Staff (4, 1)	No staff to help with luggage, impossible to travel alone. (-)
	The ticket collector helped me all the way to the train. Then I could manage to travel. (+)
On and Off Vehicle (Sum 6)	
x Physical Environment (2, 0)	Difficult to get on bus with walker and groceries, have to lift the walker.
x Staff (4, 0)	Bus driver does not use the kneeling function although I have a walker. (-)

Onboard (Sum 22)	
x System Flexibility (1, 0)	Not allowed to bring a bicycle on train, therefore I have to take the car into the city. (-)
x Phys Environment (13, 3)	The bus is lurching. Difficult to fend off with a stiff leg. (-) Nice environment on commuter trains and long-distance trains. Can look out and move around. (+)
x Information (1, 0)	Train stopped. No information about the delay, the reason for it or how long it would be. Couldn't tell my daughter when to come and fetch me. Wondered what had happened. Stressful. (-)
x Fellow Passengers (2, 0)	Noisy school classes. Nobody tells them to be quiet. I get off. (-)
x Staff (2, 0)	Bus driver starts before I have sat down. (-)
More than 1 part of Trip (Sum 12)	
x Phys Environment (1, 0)	Train reminds me of steam locomotives from childhood, connected to bad memories. Makes me feel sick.
x Information (1, 0)	Misinformation. I had been told that the train manager would help me but that was wrong.
x Fellow Passengers (3, 0)	Avoid certain underground stations late at night. Feel unsafe if there are few persons or only men on the platform.
x Staff (1, 0)	No staff at the platform to help with luggage and walkers. Have problems with my back and cannot lift my case. Am more or less locked in my cage.
x Time and Connections (4, 2)	Several changes of means to my destination. Therefore, I use the mobility service (taxi service for persons with functional limitations).
Sum Total	**78**

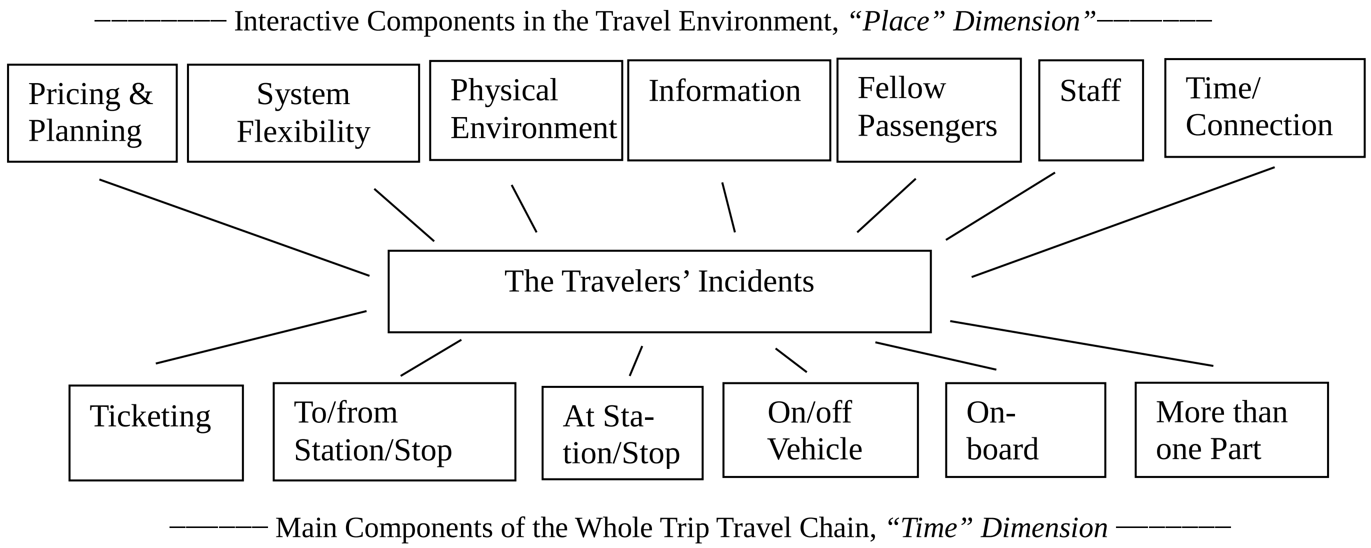

Figure 1. Interpretive Framework for categorization of Critical Incidents (CI)

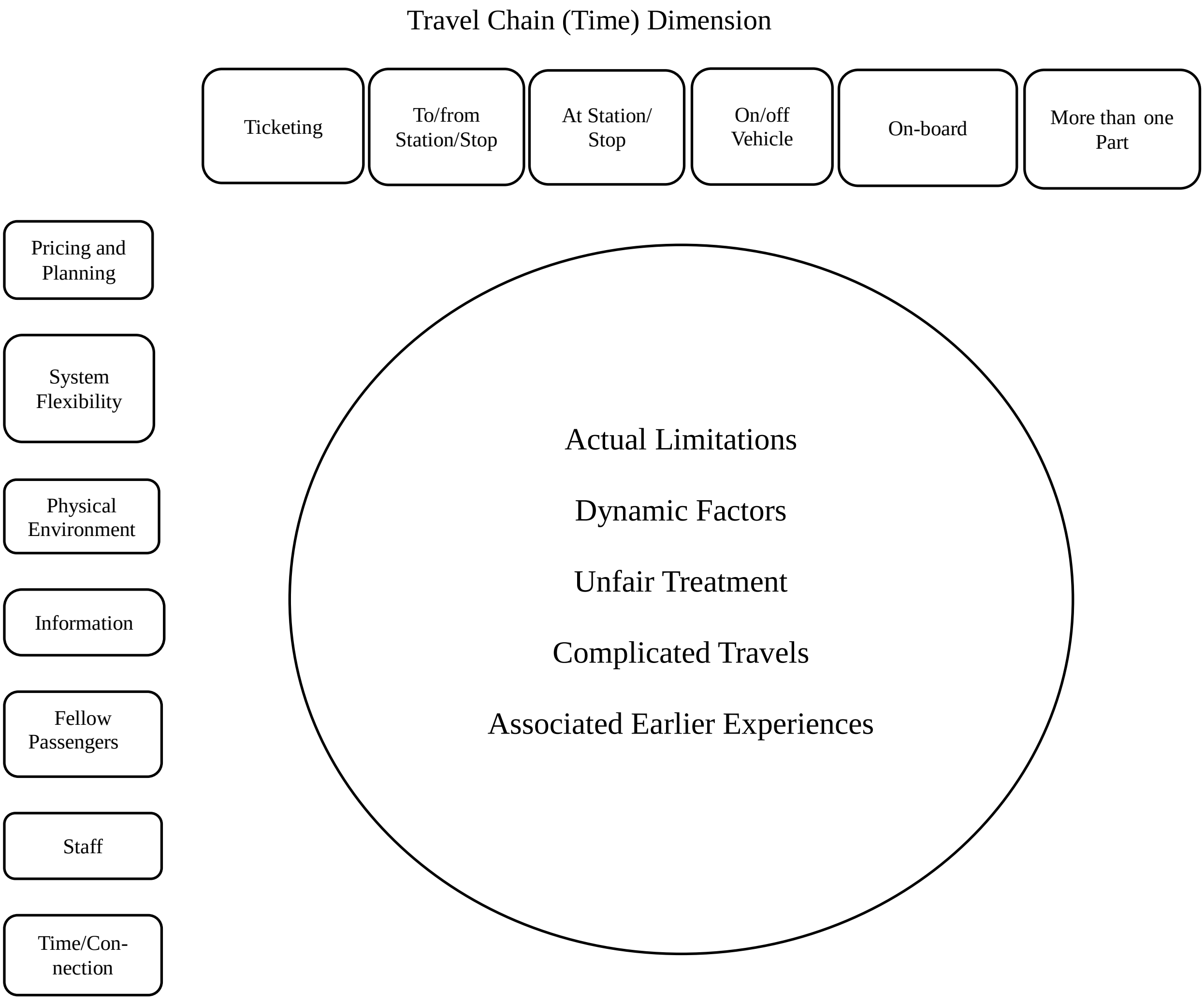

Figure 2. Responses to Negative Critical Incidents.

APPENDIX A

Coding instruction

Interviewees are 65-85 yrs of age and have been traveling by train (all rail-bound means) the last two years and have some kind of functional limitation or have traveled with luggage or with children under 6 years old.

Inclusion criteria for a critical incident are that:

- It consists of an event that influenced the experience of the trip (positively or negatively). Even repeated events in which the interviewee do not remember occasional episodes should be included. It may regard descriptions of how it ”usually is”.
- The incident occurred during a trip that was made, at least in part, by train (all rail-bound means).
- It could have occurred anytime during the trip chain, from the planning stage until the traveler reached the final destination.
- The interviewee must have experienced the incident herself/himself.
- It must have occurred during the last 2 years.

1. Decide which descriptions of events, in the interviews, you judge to be incidents.

2. Place the incidents in the categories below. An incident should be placed in only one of each dimension. If some incidents do not fit the criteria, put it aside.

Dimension A

Physical Environment
Pricate Economy
Staff
Information
Time/Connections
Fellow Passengers
System Flexibility

Dimension B

Ticketing and Planning
To Station/Stop of Departure and from Station/Stop of Final Destination
At Station/Stop
On/Off Vehicle
On-bord
More than 1 of the above/Not Specified/Whole trip

3. We compare our incidents and categories. For differences in sorting, we will discuss them until we reach a solution.

APPENDIX III

Measurements of perception: accessibility in railway transport system for travelers with and without functional limitations, Sundling, Nilsson, Berglund, Pendrill, Emardson,"15 International Congress of Metrology" Paris, 2011.

Measurements of Perception, Case study: Accessibility in railway transport systems for travellers with and without functional limitations. Les mesures de la perception, l'étude de cas: Accessibilité des systèmes de transport ferroviaire pour les voyageurs avec et sans limitations fonctionnelles

Catherine Sundling[1], Mats E Nilsson[1], Birgitta Berglund[1], Ragne Emardson[2] and L. R. Pendrill[2]

[1]**Department of Psychology, Stockholm University and Institute of Environmental Medicine, Karolinska Institutet, SE-106 91 STOCKHOLM (SE)**
birgitta.berglund@ki.se
[2]**SP Technical Research Institute of Sweden, Measurement Technology, Box 857, SE-50115 Boras, Sweden,**
leslie.pendrill@sp.se

Key Words / Mots Clés: Measurement, Perception, Accessibility, railway transport, travellers, functional limitations/
Mesure, Perception, l'accessibilité, transports ferroviaires, voyageurs, limitations fonctionnelles

Abstract

New methodologies to measure the extent to which rail passengers, even those with functional limitations, can access transport systems as a part of the whole trip, are being developed in this project. Adapting railway systems to persons with disabilities is a government priority.

This development is in part stimulated by recent increased interest in measurement systems where a human being plays a more active role than that of 'passive' operator in traditional engineering situations. Regarding Man – either as a measurement 'instrument' or even as the actual object of measurement – particularly in situations where the human being is a critical element (for reasons of safety or health for example), led the EU MINET consortium to consider commonalties and differences in (i) terminology; (ii) measurement methods; (iii) measurement uncertainty and (iv) decision-making in an interdisciplinary manner. A unique constellation of researchers from metrology, physiology, psychophysics, psychology and sociology was brought together in this recently completed, three-year EU research programme – NEST Measuring the Impossible – (2006 – 2009).

Novel approaches adapting classical metrological concepts to the measurement of the construct *accessibility* in railway transport systems for travellers with and without functional limitations. We address this issue and discuss on how to obtain quality assured measurements of accessibility. We focus mainly on the accessibility definition, the validity of the measurements and the measurement uncertainty. By defining an accessibility measure that is multiplicative, we obtain a measure that represents the different barriers persons can face when travelling.

Measurements will be used to evaluate accessibility and to target improvements in areas where they have the greatest impact. In order to improve accessibility and usability, a first prerequisite is to define the central concepts, especially in relation to railway travel and to review how accessibility and usability has been measured previously.

Introduction

A unique constellation of researchers from metrology, physiology, psychophysics, psychology and sociology was brought together [1] in a recently completed, three-year EU research programme – NEST Measuring the Impossible – (2006 – 2009) [2] to consider measurement systems where a human being plays a more active role than that of 'passive' operator in traditional engineering situations. Regarding Man – either as a measurement 'instrument' or even as the actual object of measurement – particularly in situations where the human being is a critical element (for reasons of safety or health for example), led the MINET consortium to consider commonalties and differences in (i) terminology; (ii) measurement methods; (iii) measurement uncertainty and (iv) decision-making in an interdisciplinary manner [3, 4, 5].

In an increasing number of regulatory fields, traditional physiologically-based regulations are now adding human factors such as cognitive ability, reflecting the fact that human responses need also to account for psychophysical, mental and behavioural processes in critical applications. For instance, the UK's Health & Safety Executive [6] in tackling hazardous installations in the onshore and offshore industries, takes a specifically "Human Centred" approach. Decisions about whether a human is performing reliably as an 'instrument' (e.g., as part of a control room) or whether she is in good health need to be based on quantification of these physiological and psychophysical effects in an objective and comparable manner.

To obtain this, it is necessary first to define properly suitable measurands and then provide, where possible, their traceability to appropriate SI units. Guidance on the evaluation of measurement uncertainty also needs to be developed in some cases, for instance where physiological measurands are referred to diverse measurement scales such as the ordinal or where measurements are qualitative and/or multivariate.

The earlier EU programme has stimulated continued collaboration in diverse constellations in research about the metrology of perception. The present work reports one such case where a three-year post-graduate study has been initiated in Sweden during 2010 – in a joint effort between Stockholm University, Department of Psychology (team of Prof Birgitta Berglund) and SP Measurement Technology with the support of the Swedish Transport Administration – aimed at measuring human perception of accessibility throughout a rail journey – from initial planning, through actual travel, to the destination.

Rail travel and hinders

The Swedish Transport Administration has the governmental assignment to adapt the railway system to persons with disabilities. Since barriers also affect the increasing number of persons with ordinary frailness from old age, it has been decided that they should also be included in this group, as well as children, parents with baby carriages or passengers with heavy luggage. In other words, the environment should be designed for everybody. Regarding the present study, project plans state that various measures can be implemented to improve accessibility, but it is not obvious which actions have the greatest positive impact and are most cost-effective.

Limits to innovation

Innovative research means there is no shortage of high-technological travel aids, which might be used to supplement accessibility throughout a rail trip, and new devices are being launched in major initiatives such as the EU programme Ambient Assisted Living.

However, many conclusions of the seminal work "Electronic travel aids: New directions of research" [US Commission on Vision, 1986] are still just as relevant today: "The field of mobility assessment is in disarray. There is an absence of controlled studies of mobility skills. There is an incomplete understanding of electronic travel aids, training methods, and other factors on mobility. This situation is due in part to the fact that the field has failed to adopt a standardised method for assessing travel performance."

Accessibility: definition & modelling

The purpose of the project is to develop a methodology to measure the extent to which passengers, even those with functional limitations, can access the rail transport system as a part of the whole trip. Measurements will be used to evaluate accessibility and to target improvements in areas where they have the greatest impact [7]. In order to improve accessibility and usability, a first prerequisite is to define the central concepts, especially in relation to railway travel and to review how accessibility and usability has been measured previously.

The present project is developing novel approaches adapting classical metrological concepts to the measurement of the construct *accessibility* in railway transport systems for travellers with and without functional limitations.

The measurements will also be used to target improvements in the areas where they have the greatest positive impact. By using such methods, the measurements will be used for decision making about what action should be done to make the rail transport system more accessible to the disabled. In order to make decisions on travellers' accessibility it is necessary to measure accessibility using quality assured techniques. As we have recently reported [8], the steps below constitute a chain of events useful in order to measure "new" parameters, such as accessibility

- Definition of the construct accessibility
- Identification of measurement devices and techniques
- Assessment of the validity of the measurements
- Definition a reference to make measurements traceable
- Identify the scales of measurements [9]
- Evaluate the uncertainty of the measurements
- Assess risks for incorrect decisions of conformity

We can find different definitions of accessibility in the literature. Weibull [10] presents four examples, for example, accessibility as the potential of opportunities, and the ease with which an activity can be reached. In Church *et al.* [11], accessibility is defined as a probabilistic choice based measure:

$$A_{ij} = \sum_b p_{ijb} d_{ib}^{-\beta} \quad (1)$$

where

- A_{ij} is the accessibility of person i with regard to destination j
- d_{ib}: barrier number b for person i
- p_{jb}: probability to face barrier b going to destination j
- β is a weighting parameter

In new work just reported [8], our group has proposed and investigated a multiplicative accessibility instead of an additive, this is changed. We model the measured accessibility as:

$$A_{ij}^m = \prod_b (1 - p_{jb}\psi_i(d_b)) \quad (2)$$

where

- A_{ij} is the accessibility of person i with regard to destination j
- d_{ib}: barrier number b for person i
- p_{jb}: the probability to face barrier b going to destination j

Measures of accessibility can either be judged by observing the choice and effort expended (Measuring Man) or by rating the perceived effort (Man as a Measurement Instrument) of each route. Following Weibull [10], we use an accessibility indicator in order to find numerical measurements of the accessibility. The accessibility indicator is a real-valued function ϕ defined between 0 and 1. ψ is the corresponding *measured* indicator. The values can be interpreted as the probability that a journey would be cancelled facing such a barrier. Thus the function value 1 indicates a barrier such that the probability of cancelling the journey is 100% when facing such a barrier. A value of 0 indicates the opposite, i.e., the barrier cause no problem to the traveler.

For a group of travellers, the measured accessibility is written as:

$$A_j^m = \sum_i \hat{p}_{ij} \prod_b (1 - p_{jb}\psi_i(d_b)) \quad (3)$$

where $\hat{p}_{ij}$ is the probability that person i is going for destination j.

In [8] we focus mainly on the accessibility definition, the validity of the measurements and the measurement uncertainty. In order to assess our measurement model and its associated uncertainty, we simulate the situation with twenty barriers (which could be for instance: difficulty booking the travel on the internet; problem accessing the rail coach; limited ability to read signs etc.) and a selected group of travellers formed by a selection process.

Acknowledgments

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APPENDIX IV

New perspective on the accessibility of railway transport for the vulnerable traveler, Sundling, C., Berglund, B., Nilsson, M.E., Emardson, R., & Pendrill, L., Journal of Physics: Conference Series, Vol 459, 012021, 2013.

New perspective on the accessibility of railway transport for the vulnerable traveller

C Sundling[1], B Berglund[1,2], M E Nilsson[1,2], R Emardson[3] and L Pendrill[3]

[1]Department of Psychology, Stockholm University, SE-106 91 Stockholm
[2]Institute of Environmental Medicine, Karolinska Institutet, P.O. Box 210, SE-171 77 Stockholm, Sweden
[3]Measurement Technology, SP-Technical Research Institute of Sweden, P.O. Box 857, SE-501 15 Borås, Sweden

E-mail: catherine.sundling@psychology.su.se

Abstract. Vulnerable travellers experience various problems in the transport environment. These may reduce public travel confidence and consequently lead to decreased mobility. A goal of our research is to find out how to improve the accessibility to railway travelling, especially, for persons with functional limitations. By reducing barriers, the ability of travelling would be improved, and consequently allow for more flexible travel behaviors. In order to develop a model and a method of measurement for accessibility, we (a) constructed a reference group of representative *'typical older persons'* (65-85 years) from questionnaire data, and (b) developed an accessibility measure for persons with functional limitations. In this measure barriers have different weights for the different persons depending on their functional ability and travel behavior. This gives the probability of facing a certain barrier when travelling to a certain destination; that is, a measure of accessibility for the individual. The more weight placed on a certain barrier, the less probable it is that the particular journey will take place. These weights will be obtained in forthcoming research on the perception of a set of various travel scenarios representing barriers.

1. Introduction

An overall goal of our research is to find out how we may improve the accessibility to railway travelling for persons with functional limitations. For the group of "vulnerable travellers" different kinds of functional limitations lead to different problems in the transport environment; covering the whole trip, from start to arrival at the intended place of destination. Traditionally, transportation research has been conducted with "mainstream" travellers who are viewed as interchangeable. But, the experience of the travel environment and its impact will differ among individuals, depending on where and when travel takes place. For the group of "vulnerable travellers" different kinds of functional limitations will lead to various problems in the transport environment. For instance, persons with cognitive impairment, involving stroke, dementia and brain injuries, often face specific accessibility problems such as coping difficulties in an increasingly changing travel environment. Also the elderly may have problems with our computerized information society. This can reduce public travel confidence and consequently lead to decreased mobility. Moreover, the severity of each type of functional limitation as well as other factors such as earlier travel experiences and factors related to personality, would certainly affect the interpretation of the travelling situation. Therefore, a focus on the individual with his/her specific or manifold of functional limitations would reveal needs that are disguised in the larger population. Moreover, it seems wise to include persons that are *not* travelling, because they already encountered insuperable barriers in travel environments. Without these would-be passengers, the most important factors might be missed among those that ought to be improved in the travelling system.

2. The concept of accessibility

There is no definition of accessibility that is uniform or generally accepted. Gould [1] describes it as "a slippery notion", that is a common concept widely used until faced with the problem of defining and measuring it. Accessibility research is found in i.a. geography, economics, occupational therapy and psychology, and its definition differs depending on the goal of the research. For example, in the United Kingdom [2], the concept of accessibility for persons with impairments is used in two different contexts: either to describe design characteristics that improve (or prohibit) the travelling or to describe the ease of reaching an intended destination. 'Accessibility' is used as a quantity in planning for measuring how the travel chain in a transport network performs for various groups of passengers. Even though its definition has not become uniform and generally accepted, the main distinction in recent definitions is that accessibility is an attribute of people *and* of places [3].

3. Accessibility measures

Not only are there many different definitions of accessibility, there are also many different ways of measuring it. Depending on scientific discipline, different ways of measuring accessibility have developed that capture different aspects or dimensions of the concept [4]. Thus, there is no consistent terminology for describing the various methods of measuring accessibility. However, it is fruitful to distinguish between two accessibility constructs: *place* accessibility and *individual* accessibility.

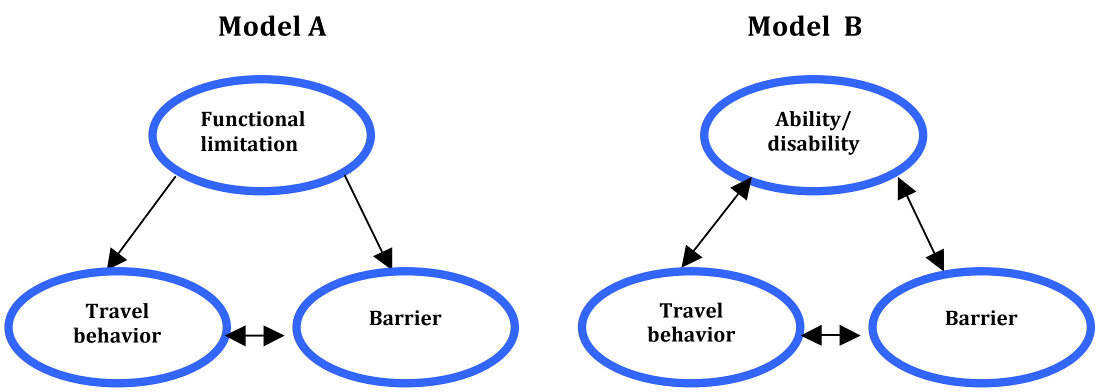

Figure 1. Accessibility may be modeled for travellers' functional limitations (Model A) or for travellers' abilities and/or disabilities (Model B). Please note that functional limitations are invariant relative to travel behavior and the barriers, whereas abilities/disabilities instead are variant owing to reciprocal interactions.

The measurement model for place accessibility is primarily based on various characteristics of the transport and geographical (physical) place, whereas individual accessibility is based on a set of features of each traveller in the transport system [2]. In our research, we focus on the measurement of *individual accessibility* (Figure 1).

A 'functional limitation' constitutes a physical, psychological or intellectual reduction in human function. It is a temporary or permanent condition in individuals. Alternatively, 'disability' is defined as the product of interactions among individual features and environmental characteristics [5]. Disability may involve anything from inaccessible information to physical design characteristics like staircases or doorsteps and/or psychological features like attitudes of fellow passengers or staff. The same functional limitation may thus, in interaction with one environment, but not another, become a disability.

A 'barrier' constitutes i.a. a physical, psychological, social or economic constraint in the travel chain, experienced by the individual passenger. Examples of barriers are design deficiencies of stations, trains and time-table information as well as delays. Over time, the set of barriers will vary for one traveller as well as among travellers. For example, if one traveller has already encountered a barrier during a trip, a subsequent barrier (the same kind or a new one) might well be perceived even worse than the previous one.

In the present research context, 'travel behavior' refers to the way persons use different means of transport. Here, we focus mainly on travel frequency and travel mode. In Sweden and in many other countries, car is the most frequently used travel mode. Thus, measured as number of movements per day, the car stands for 38% (drivers) and 15% (passengers). Car use declines with increasing age as does mobility in general. Among the Swedish car users in the age group 65-84 years old, men and high-income earners have more often a driver's license and own a car. Only 0.7% of all journeys are by railway [6]; see also [7] and [8]. The most common reasons for old persons' travels are shopping, physical exercise and recreational activities [9].

Rimmer et al [10] developed the AIMFREE set of psychometric measuring instruments for persons with functional limitations. They developed and validated 16 survey instruments that measured accessibility to recreational and fitness environments. Interestingly, they utilized the Rash model for demonstrating good psychometric properties of their instrument. Also a Swedish research team has developed a supportive instrument, "The Travel Chain Enabler", for assessing urban public bus transportation accessibility for persons with functional limitations [11], [12].

4. Measurement model of accessibility

We propose a triangular model in which the accessibility to railway travelling results from interactive processes among three cornerstone constructs (Figure 1, Model A): travellers' functional limitations, barriers in the transport system, and overall travelling behavior. By replacing the invariant construct travellers' functional limitations (Model A) with the variant construct travellers' *abilities* or *disabilities* (Model B), our measurement model of accessibility will involve three reciprocal interactions instead of one. Thus, in Model B, each of the three constructs constitutes complex, multi-variable quantities (or patterns) among which reciprocal interaction outcomes are of paramount importance for measuring the quantity *accessibility*. Thus, it is fruitful to study the abilities of persons with functional limitations, rather than focusing on their disabilities. By reducing the barriers, the ability of travelling will be improved, and consequently allow for more flexible travel behaviors.

Emardson et al. [13] have defined an accessibility measure for persons with functional limitations in which barriers have different weights for the different persons depending on their functional ability and travel behavior. This gives the probability of facing a certain barrier when travelling to a certain destination; that is, a measure of accessibility for the individual. The more weight placed on a certain barrier, the less probable is the particular journey. Moreover, disability and functional limitation should be understood from the perspective of travellers' personal experience and interpretation, which may differ among individuals even if the functional limitations, and additional disabilities, are of the same kind and severity.

As said above, barriers can vary among individuals as well as for the same individual over time. For example, having encountered a barrier during a trip can result in an adverse perception of subsequent barrier. However, for simplicity we will not consider, in the following, that the perception of barriers is affected by previous situations. Using the approach of viewing barriers as constraints in the travel chain, Emardson et al. [13] modeled the accessibility reported by a person i with regard to destination j, A_{ij} as:

$$A_{ij}^{m} = \prod_{b} (1 - p_{jb} \psi_i(d_b)) \tag{1}$$

where d_b is barrier number *b* and p_{jb} is the probability of facing barrier *b* when going to destination *j* and

$$\psi_i(d_b) = \phi_i(d_b) + v_{ib} \tag{2}$$

Here, we introduce an accessibility indicator, ϕ, which is a function operating on the set of barriers, and it is defined on a scale from 0 to 1 [14]. These scale values denote the perceived effort if facing a certain barrier, and it can be interpreted in terms of the probability of cancelling a journey. The function value 1 indicates 100% probability of cancelling the journey, and the value of 0 indicates a barrier causing no problem to the traveler. The symbol ν represents the measurement noise and is a random variable, which is normally distributed with a mean value u and a standard deviation, σ_v. For a specific person and destination, the presented model is separable on the barriers. It is not additive however.

The measured accessibility for a group of travelers can then be modeled as:

$$A_{j}^{m} = \frac{1}{I} \sum_{i} \hat{p}_{ij} \prod_{b} (1 - p_{jb} \psi_i(d_b)) \tag{3}$$

Where *I* is the number of persons and $\hat{p}_{ij}$ the probability that person *i* is aiming for destination *j.* The measured accessibility will hence be a number between 0 and 1. Simulations [10] indicate a measurement uncertainty of the accessibility around 0.03 given a situation with 20 barriers. In difference to the accessibility model for a specific person, this model is not separable on the barriers.

In our study, we will use a set of persons to grade identified barriers. Emardson *et al.* [13] showed, using Monte Carlo simulations, that in order to have a standard deviation of the measured accessibility of a size typically a tenth of the measured value; we need a group of about 40 persons grading the barriers.

In order to guarantee the validity of the accessibility measures, it is important that the barriers are scaled by a representative group of persons. To find these groups of persons, we conducted a questionnaire study on perceived accessibility in the railway system. We chose older persons as the target group because functional limitations are more common with older age. Moreover, the growing number of older persons in society poses challenges to the transport system as regards services to meet the special needs of this group. From the questionnaire data, we constructed a reference group of representative *'typical older persons'* (65-85 years). They are identified by a procedure involving two stages: Stage 1, persons are removed who are very dissimilar from the typical 'older train traveller' on the basis of binary coding of a large number of criterion variables. Stage 2, participants are selected on the basis of fuzzy resemblance of the typical 'older person' on the most important criteria (see further [15]).

With the reference group constituted and in place, individuals are recruited for an interview study. The research goal is to explore the range of barriers encountered in the railway system and how they are perceived. The respondents are selected based on inclusion criteria for the reference group (age, gender, travel frequency, travel mode, etc.). Thus, persons would be included who have various functional limitations and represent a wide range of travel behavior. We will explore the range of barriers encountered by them. The different kinds of barriers would be measured according to Eq. 1, which delivers *individual accessibility measures*. This is accomplished by putting a perceived-effort weight on each barrier for each individual. These weights will be obtained in forthcoming research on the perception of a set of various scenarios representing barriers.

Acknowledgments
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APPENDIX V

Two Models of Accessibility to Railway Traveling for Vulnerable, Elderly Persons, C. Sundling, R. Emardson, L. Pendrill, M. E. Nilsson, and B. Berglund, submitted to Measurement.

Two Models of Accessibility to Railway Traveling for Vulnerable, Elderly Persons

C. Sundling[a,1], R. Emardson[b], L.R. Pendrill[b], M.E. Nilsson[a, c] and B. Berglund[a, c]

[a] *Department of Psychology, Stockholm University, SE-106 91 Stockholm, Sweden*
catherine.sundling@psychology.su.se; mnn@psychology.su.se
[b] *Measurement Technology, SP-Technical Research Institute of Sweden, P.O. Box 857, SE-501 15 Borås, Sweden*
ragne.emardson@sp.se; leslie.pendrill@sp.se
[c] *Institute of Environmental Medicine, Karolinska Institutet, P.O. Box 210, SE-171 77 Stockholm, Sweden*
birgitta.berglund@ki.se

Abstract

In public transport, vulnerable travelers would meet barriers that may restrict mobility. Such barriers are best identified by the vulnerable travelers themselves, e.g., those with functional limitations. We show that elderly travelers' functional ability can be improved by reducing or removing appreciable barriers in the travel chain, thus creating more flexible and independent travel behavior. For a traveler, a theoretical model for accessibility constitutes a three-way reciprocal relationship among functional ability, barriers and travel behavior. For the whole trip, here targeting railway traveling, accessibility is modeled by travelers' individual weightings of potential barriers, which in turn depend on travelers' functional abilities. A traveler's overall accessibility measure for a journey is constructed from the weight of each barrier and the probabilities of encountering the different barriers when traveling to a certain destination (travel behavior). We conclude that customized abatement procedures must accomplish better accessibility for all, especially for the vulnerable travelers.

Keywords: accessibility, functional ability, barrier, travel behavior, the elderly

1. Introduction

1.1 Vulnerable travelers

Our research goal is to develop a methodology with which to measure accessibility in the public transport environment for vulnerable travelers. An overarching aim is to achieve an improved accessibility in the transport environment by enabling more flexible and independent travel behavior. For various reasons, a traveler may be vulnerable in the transport environment. Old age or functional limitations, such as restricted mobility, cognitive and psychiatric deficits or sensory impairment may enhance potential barriers in the transportation system and thus hinder traveling. Moreover, traveling with children or with heavy luggage may imply a greater vulnerability. We focus in the present study on elderly persons with functional limitations.

Because of the heterogeneity of the group of vulnerable travelers, research needs to adopt an individual approach to capture their needs [1]. Different kinds of functional limitations lead to different problems in the transport environment. For example, persons with cognitive impairment, as a result perhaps of stroke and dementia, may face specific accessibility problems in trying to cope with the ever-changing travel environment. Also, the elderly may have problems with the increasingly computerized

[1] Telephone number to corresponding author: Catherine Sundling, +46703339330.

solutions typical of today's travel environment. Moreover, the severity of a functional limitation as well as other factors such as earlier experiences and personality, can influence the interpretation of, and the ability to cope with, the travel situation. A focus on the individual might reveal needs that would be hidden in a larger population. Specifically, there is a need for more knowledge about how older persons *experience* traveling; for example what emotions and meanings are ascribed to travels [2].

Mobility, including accessible transport, enhances the quality of life for many elderly persons [3,4,5]. Increased mobility may reduce the risk of social exclusion, that is, in turn, associated with well-being of the individual [6]. In particular, persons without a driver's license; those living in rural areas; and the women, have been found to have unfulfilled travel needs [1,7]. Because of the strong association between car driving and mobility, as a group, older women are more vulnerable and dependent on others since they more often do not have a driver's license. As a majority in the oldest old, the women are also more vulnerable than men.

In addressing potential barriers, the whole travel chain must be taken into consideration, from the start to arrival at the intended destination. Therefore, also outdoor environments are included, such as the way between a person's home and means of transportation. Moreover, the remoteness of public transport may be critical for accessibility; for example, Kim and Ulfarsson [8] found that older persons were more likely to use public transport if they lived closer than five blocks from a bus stop. Moreover, connecting travel means may create barriers for some travelers, and, with increasing age, travelers tend to make less complex trips, especially over the age of 85 [5].

In research on accessibility for travelers in public transport, it seems wise also to include persons who are *not* traveling because "they have already encountered too serious barriers" (inclusion criterion). Without including these would-be-travelers, the most influential factors for accessibility might be missed; an example could simply be "the necessity to use an elevator instead of a staircase".

1.2 Accessibility

There is no agreed upon way of defining and measuring accessibility. However, a major division is often made between *place* accessibility and *individual* accessibility [9]. Place accessibility refers to characteristics of the physical place, whereas individual accessibility refers to features of a person, e. g., a traveler in the transport system. Here, we focus on *individual accessibility* and therefore, accessibility is measured with the individual as the measuring instrument.

An earlier attempt to measure accessibility is the AIMFREE by Rimmer et al. [10]. It consists of a set of psychometric measuring instruments for persons with functional limitations. In all, they developed and validated 16 survey instruments for measuring accessibility to recreational and fitness environments. By applying the Rasch model [11,12], Rimmer et al. [10] demonstrated that their instruments had good psychometric properties. In a separate publication, we report on a psychometric Rasch modeling of transport accessibility, based on a survey sample of about 1000 elderly travelers with functional limitations. This model enables estimates of separate measures for place and individual accessibility attributes [13].

Notably, Iwarsson, Jensen and Ståhl [14] had earlier developed an instrument named "The Travel Chain Enabler" and combined it with "The Critical Incident's Technique". This new instrument has been used for researching accessibility to urban public bus transportation for persons with functional limitations [15]; see also [16,17].

2. Theoretical model for accessibility

In Figure 1, we have developed a theoretical person-environment-interaction model for accessibility to railway transport [18,19,20]. Model A presents perceived accessibility as a function of travel behavior and of barriers (constraints) for persons with *functional limitation(s)*. A functional limitation is regarded as a *person factor*, inherent in the person. It will affect what *barriers* are encountered during whole-trip traveling as well as what *travel behaviors* are provoked. For example a broken leg would make climbing stairs more difficult. Notably, for different persons, the identical functional limitation may create different travel behaviors, e. g., one person may avoid stairs (=barrier) altogether, another may choose to climb the stairs more carefully (travel behavior in interaction with barrier). Moreover, depending on situation and occasion, the same barrier may be perceived differently by the same person and thus result in various travel behaviors. Please observe that even if barriers are reduced or removed, the functional limitation would still be the same; the causation is one-sided.

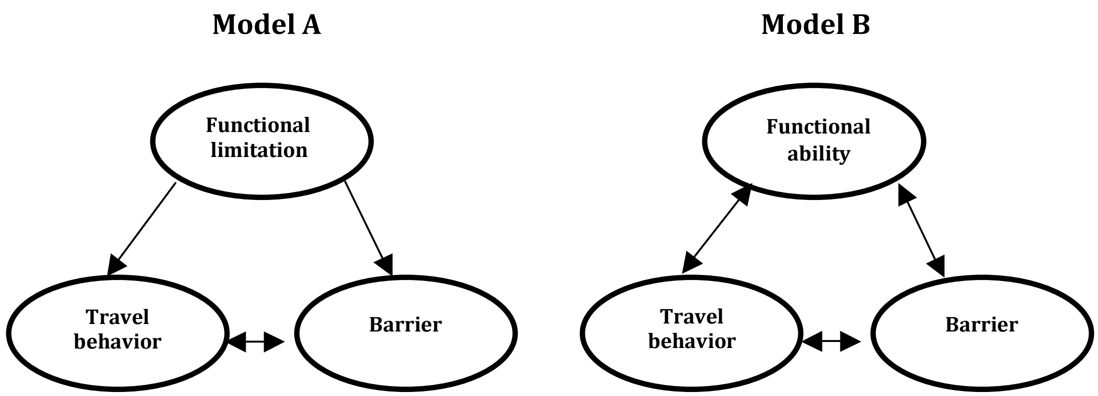

Figure 1. Perceived accessibility to whole-trip traveling modeled for travelers with various kinds of functional limitations (Model A) or for travelers with various degrees of functional abilities (Model B).

As proposed in Model B, it is fruitful to focus on persons' functional *abilities*, rather than merely on their functional limitations (Model A). In the case of functional ability, the causation turns into a three-way reciprocal relationship. Model B exhibits accessibility to the whole trip as (a) travelers' functional ability, (b) their perceived barriers in the travel environment, and (c) their travel behavior. Functional ability is a feature that emerges in a person's *encounter with her/his environment*. If barriers are reduced or removed, the functional ability may increase (and travel behavior may become more independent). The causation may also work the other way around; the barriers may change because of a person's level of ability (bi-directed interaction). Consequently, the travel environment may change because of a person's particular level of functional ability. That is, not only does the barrier influence a person's ability, but the person may also influence the barrier. The staff may treat a person with low ability differently than a person with high ability. For example, before driving off, a bus driver may kneel the bus or wait until a person with seemingly low ability has found a seat. The low ability here resulted in a reduction of the barrier. A more common situation would be that a person with a low ability encounters more barriers than a person with a high ability.

Although functional ability is regarded as a feature appearing in the person-environment interaction [21], it is grounded in person factors such as functional limitations and physical characteristics but also in intra- and inter-psychological factors such as personality, self-perception, and attitudes towards others. In addition, functional ability would depend on age, gender, own economy, and socioeconomic factors [22]. Moreover, the traveler's geographical location in relation to available public transport will influence his/her ability to travel. As expressed in Model B, functional ability cannot express itself unless it co-exists with traveling behaviors and potential barriers met in the travel environment. Therefore, a barrier may be perceived differently by different persons as well as by the same person in different situations and at different times. Functional ability is thus a dynamic factor, created in the situation and dependent on complex structures in the person and in the environment. Moreover, the expectations of the consequences following a potential future behavior, helps shaping functional ability. A person chooses a certain travel behavior and then evaluates it; expectations are then formed regarding future behavior that would depend on how the person's own ability is perceived [20]. Therefore, motivation is a feature that may result from earlier travel experiences and it also becomes part of the ability, for example through self-perception. Feeling unable is an experience that may reduce motivation to travel again in the same way.

2.1 Functional ability and travel behavior

Ability may influence *actual* traveling, but the opportunity to travel[2] may also be of importance for ability. It can be hypothesized that the mere possibility to travel, even if the specific travel behavior is not realized, may have a positive impact on well-being. Functional ability naturally influences travel behavior, but travel behavior also changes the person's ability. As pointed out above, by traveling more frequently, the traveler learns how to overcome certain barriers and thus may enhance his/her functional ability, e g how to use the ticket machine, or how to find the right bus stop in time. Therefore, the travel behavior itself, may also improve functional ability.

2.2 Barrier and travel behavior

The *barriers* encountered may influence travel behavior, which in turn becomes more flexible and independent if adequate barrier reductions are accomplished in the travel environments. Having met certain barriers when traveling, we might travel by one mode or another, and/or at certain preferred times of the day. Thus, to a certain extent, we "choose" the barriers we would encounter during a trip and thus also the barriers that will affect us. Probably, we would try to avoid serious barriers in traveling. In planning our trip, we imagine how the trip will unfold and this would of course support forthcoming decisions regarding traveling.

According to the theory of planned behavior [24], a person's future (travel) behavior would be guided by: (a) beliefs about favorable or unfavorable consequences of travels that would help shaping attitudes regarding the future travels, (b) normative expectations of others, e. g. regarding mode of transport, and (c) beliefs about factors (e. g., electronic information on trip; ticketing) furthering or hindering traveling behavior, which in turn affects the perceived level of behavioral control and, consequently, the perceived ease or difficulty to perform the behavior, e. g., to manage the whole trip, from door to door. Typically, the more favorable the attitudes and norms and the higher the perceived control, the stronger is the intention to perform a behavior. In addition, past behavior supports prediction of future behavior, but only when circumstances remain relatively stable, that is, when no relevant, persuasive and new information is added [25]. If there are changes, a new situation is created and the behavior must be predicted within that particular new frame of reference. Please observe that global, situation-free consistencies in behavior do not exist [26].

So far, we have shown how travel behavior is affected by functional limitations, functional abilities and barriers. Now, we present how travel behavior may affect the barriers. There are two kinds of conditions: one where the travel behavior helps the traveler to overcome barriers in the travel environment, the other where the travel behavior will change the travel environment itself. An example of the first case is that more frequent traveling would improve way-finding to the designated platform at the railway station; the second case that a fellow passenger would offer his/her seat to an elder passenger with a walker entering the railway carriage.

2.3 Functional ability, barrier and travel behavior

In our model, *barriers* are regarded as environmental properties in the person-environmental model. They are experienced and thus assessed by the traveler. Consequently, the same barrier may assume different perceptual values for different travelers. For each traveler, the severity or *weight* of a barrier depends on the *perceived effort* when facing the barrier while traveling. If more effort is required for a specific barrier, *functional ability* needs to be higher than if less effort is needed. Moreover, travelers have

[2] The 'supply' of travels, reachable for a specific individual (cf. [2,23].

expectations on how a future trip may turn out. Therefore, barriers that would not be encountered in the real environment, but rather exist in the persons' minds as perceptions, could be a hindrance for the traveling [27]. Additionally, all barriers are not equally often encountered in trips. Thus, the *probability* of encountering a specific barrier at a specific trip (travel behavior) will also influence the perceived accessibility.

3. Mathematical-empirical model for accessibility

The model we use for accessibility is based on the individual person's perceived effort when facing a certain barrier together with the barriers they actually have to overcome during a journey. Using this approach, Emardson et al. [28] model the measured accessibility (A_{ij}) for person i traveling to destination j as:

$$A_{ij}^{m} = \prod \left[1 - p_{jb}\psi_i(d_b)\right] \tag{1}$$

This accessibility model contains measurements of the perceived effort, ψ_i, for person i facing a certain barrier, d_b, and the probability, p_{jb}, that a person will face the barrier, d_b, on the way to destination j. The measured perceived effort for person i, in overcoming barrier d_b, is a function of the true value, ϕ, and an error component ν.

$$\psi_i(d_b) = f\left[\phi_i(d_b), \nu_{ib}\right] \tag{2}$$

The true value, ϕ, is a function for each person i, operating on a set of barriers d. The true value is of course impossible to know, but we can still assume the existence of it. The error component ν is a random variable, which is Normally distributed with a mean value υ and variance, σ^2_ν. The perceived effort function ϕ is defined between 0 and 1. These values can be interpreted as the probability that a journey would be cancelled facing such a barrier. Thus, the function value 1 indicates a barrier such that the probability of cancelling the journey is 100% when facing such a barrier. A value of 0 indicates the opposite, i.e., the barrier causes no problem to the traveler.

In this paper, we use a linear measurement model. That is, the relation between the measured perceived effort for each barrier and the true value can be written as:

$$\psi_i(d_b) = \phi_i(d_b) + \nu_{ib} \tag{3}$$

When evaluating accessibility, it is central that the measurements do not vary with time. One of the fundamentals in measuring, for example accessibility, is to determine if changes in the infrastructure have improved the accessibility for the travelers or not. In order to be able to state that an improvement has taken place, we need to know that one measurement of the accessibility one year can be compared to another measurement another year. In physical measurements this is attained by relating relevant quantities to national or international standards through an unbroken chain of measurement comparisons [29]. For measurements with persons as measuring instruments, we would like to have a similar system. There are, however, no international standards similar to the international SI-system. Hence, we need to find alternative ways of setting up systems that allows comparisons over time and between countries.

In order to find a scale that does not vary in time, we need to find reference barriers that can be considered to have an effect constant over time. The technique of master scaling was developed by Berglund [30,31] in order to be able to obtain one perceptual measurement from one person at one occasion and be able to compare it to one perceptual measurement from another person at another occasion. In order to find references independent from the measurand, Berglund and Nordin [32] used a cross-modal reference, the loudness of pink noise, in measuring odor intensity of pyridine for smokers and non-smokers. Thus, a set of loudness perceptions served as references in scaling perceived odor intensity in each of the two subject groups with presumed differences in odor sensitivity.

For accessibility measurements, we need reference questions that do not vary over time. The ideal situation would be to find some eternal values. Fowles [33] states, however, that "there are, unfortunately, no eternal truths. The hallowed truths and values that regulate the lives of all humans vary greatly in time and space". Instead, we need to find ways to get around this problem. Fowles [33] recommends that "one should take account of the fact that future values may fluctuate and proposes several different future value sets." As the subject will scale the barriers based on a probability that the specific barrier will avert the journey, the problem is similar to Seidenfeld's [34] description of calibration. He defines calibration as "A set of probabilistic predictions are (well) calibrated if *p* percent of all predictions reported at probability *p* are true." An alternative approach is to use specific references that we know for certain have not changed since the previous measurement. Using these specific references we want to estimate the matrix υ. In order to perform this, we can define a set of fixed values based on a well-defined scenario, for example mock-up models of barriers, preferably at the same time not affected by the abilities (or attitudes) of particular persons. For these barriers we can specify reference target values, ζ, knowing that the value 1 indicates that the barrier for certain will prohibit the journey and that the value 0 indicates that the barrier will pose no problem for the traveler. By using the values for the indications by our set of test persons at the well-defined scenario, τ, and the reference values, we can estimate the measurement error, υ, as the mean difference, μ, between τ and ζ for each pair of combination person-barrier (*ib*). That is:

$$\hat{\upsilon} = \mu_{ib} = \tau - \zeta \quad (4)$$

Inserting the expression for the corrected indication adding μ to Equation (1), we obtain a corrected calibrated measure of accessibility as:

$$A_{ij}^{m} = \prod_{b} \left[1 - p_{jb}\left(\psi_i(d_b) - \mu_{ib}\right)\right] \quad (5)$$

4. Conclusions

Because barriers met in travelling are perceived differently depending on various features of individuals, it is important to develop ways of measuring accessibility from the perspective of the individual traveler. Thus, it is important to include persons with various prerequisites, here introduced as *perceived effort* in their encounter with various sets of barriers during the whole trip. In this way, in the data collection, travelers with various kinds of functional limitations and degrees of functional ability will be covered together with targeted sets of barriers.

In this paper, we have extended our previous model for accessibility in railway transport [35,36]. A traveler's functional limitation (person factor) cannot be changed by the transport system but a traveler's functional ability (person-environment factor) could be improved by reducing adequate *barriers* in the travel chain. This set of barriers may best be identified by the *vulnerable travelers* themselves. Accessibility can be *measured* by applying individual weighting of the various sets of barriers for the whole trip. By counteracting significant barriers, vulnerable travelers should be able to travel more independently. Because of the enhanced functional ability, *accessibility to travel* would also be improved. Thus, to reach better accessibility for all, abatement procedures should be recommended, especially targeted for the specific groups of vulnerable travelers. Unfortunately, there is a shortage of measuring instruments for these underrepresented groups of travelers or would-be-travelers in the public transport environment.

At the societal level, a recommendation resulting from our research is to reduce barriers in the travel environment such that it becomes increasingly adapted to travelers with low functional ability, and consequently also improved. This is a "win-win situation" in that stakeholders increase the number of potential travelers, by decreasing barriers, and consequently, the travelers' functional ability will also be improved. Taken together, this chain of events would result in more flexible and independent travel behavior for all.

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APPENDIX VI

Measurement Of Accessibility To Rail Transport Systems , Emardson, R., P. Jarlemark, L. R. Pendrill, C. Sundling, M.E. Nilsson, B. Berglund, , Advanced Mathematical and Computational Tools in Metrology and Testing, vol.9 (F Pavese, M Bär, J-R Filtz, A B Forbes, L R Pendrill, H. Shirono, eds.), Series on Advances in Mathematics for Applied Sciences vol. 84, World Scientific, Singapore, 2012.

MEASUREMENT OF ACCESSIBILITY TO RAIL TRANSPORT SYSTEMS

RAGNE EMARDSON, PER JARLEMARK, AND LESLIE PENDRILL

SP Measurement Technology
Box 857, 501 15, Borås, Sweden

CATHERINE SUNDLING, MATS E NILSSON, AND BIRGITTA BERGLUND

Department of Psychology, Stockholm University and Institute of Environmental Medicine, Karolinska Institutet
106 91, Stockholm, Sweden

Improving accessibility to rail systems for persons with disabilities is a governmental assignment to the Swedish Transport Administration. In this paper, we address this issue and discuss on how to obtain quality assured measurements of accessibility. We focus mainly on the accessibility definition, the validity of the measurements and the measurement uncertainty. By defining an accessibility measure that is multiplicative, we obtain a measure that represents the different barriers persons can face when travelling.

Keywords: accessibility, measurements with persons, soft metrology, perception

1. Background

Improving accessibility to rail systems for persons with disabilities is a governmental assignment to the Swedish Transport Administration. According to Statistics Sweden, SCB [1], a fifth of the Swedish population or 1.3 millions are disabled, including vision- or hearing deficiencies, mobility disorders, severe asthma or allergy. Challenges for this group of travelers can be found at all stages of a journey, from initial planning to make the journey to arriving at the final destination. Various measures can be implemented to improve and increase accessibility for the disabled throughout the rail transport system. Which actions that have the greatest positive impact and are most cost-effective, however, is not obvious. In addition to identifying and developing a variety of measurements to locate areas of concern, the question of how the measurement should be handled in order to be able to draw appropriate conclusions has to be answered. In order to improve accessibility and usability, a first prerequisite is to define the central concepts, especially in relation to rail travel and review how accessibility and usability have been measured previously.

In a formulation by Gould[2] altered by Pirie[3] it is stated that "*accessibility … is a slippery notion … one of those common terms that everyone uses until faced with the problem of defining and measuring it*" In this paper, we address this issue and discuss on how to obtain quality assured accessibility measurements. A key aspect of the measurements of accessibility is that they involve human perception [4]. As such the methodology developed in this paper benefits from knowledge both from the disciplines metrology and psychology.

2. Methodology

In this paper, we present a methodology for measuring the extent to which passengers with disabilities can use a rail transport system as part of a whole trip. The measurement methods to be developed, particularly where a human is a key component of the measurement system, importantly provide a basis for an objective evaluation of accessibility for disabled people. The measurements will also be used to target improvements in the areas where they have the greatest positive impact. By using such methods, the measurements will be used for decision making about what action should be done to make the rail transport system more accessible to the disabled. In order to make decisions on travelers accessibility it is necessary to measure accessibility using quality assured techniques. The steps below constitute a chain of events useful in order to measure "new" parameters, such as accessibility.

- Definition of the construct accessibility
- Identification of measurement devices and techniques
- Assessment of the validity of the measurements
- Definition of a reference to make measurements traceable
- Identification of the scales of measurements.
- Assessment of the measurement uncertainty

In this paper we focus mainly on the accessibility definition, the validity of the measurements and the measurement uncertainty. Our methodology in the paper consists of four parts. First we need to find representative people in order to guarantee the validity of the measurements. Two groups will be selected. The first group which is smaller will be used to identify barriers preventing or obstructing travel. The second group will be used as measurement instruments and grade the identified barriers. Based on the grading of the barriers, we can measure the accessibility. The steps are described in more detail below.

3. Selection Process

The selection process is of great importance for the validity of the measurements. We will find representative participants forming a group of travelers by distributing questionnaires. Based on the answers, persons representing different major groups of travelers can be chosen. The participants can be chosen according to Botteldooren et al [5] which describe a method to find representative.

We can also use a hierarchical clustering approach, e.g., [6]. The selection of participants will be an essential part for successful measurements of accessibility. Details on the selection process will not, however, be covered in this paper.

4. Barriers

Based on a critical incidents technique [7], we can identify significant barriers en route to accessing the goal. The identification of the barriers are performed by the selected participants. We now have a set **M** of barriers, d_b, which the participants have identified.

Measures of accessibility can either be judged by observing the choice and effort expended (Measuring Man) or by rating the perceived effort (Man as a Measurement Instrument) of each route. Following Weibull [8], we use an accessibility indicator in order to find numerical measurements of the accessibility. The accessibility indicator is a real-valued function ϕ defined on the elements in **M**. The function ϕ is defined between 0 and 1.The values can be interpreted as the probability that a journey would be cancelled facing such a barrier. Thus the function value 1 indicates a barrier such that the probability of cancelling the journey is 100% when facing such a barrier. A value of 0 indicates the opposite, i.e., the barrier cause no problem to the traveler.

Further, we model the measurement of the barrier performed by the selected group as:

$$\psi_i(d_b) = \phi_i(d_b) + \nu_{ib} \tag{1}$$

where ν is a random variable which is normally distributed with a mean value υ and a standard deviation, σ_ν. Using such an approach, we now have values on a ratio scale [9].

5. Accessibility

We can find different definitions on accessibility in the literature. *Weibull* [8] presents four examples, for example, accessibility as the potential of opportunities, and the ease with which an activity can be reached. In *Church et al*. [10], accessibility is defined as a probabilistic choice based measure:

$$A_{ij} = \sum_b p_{ijb} d_{ib}^{-\beta} \quad (2)$$

where

- A_{ij} is the accessibility of person i with regard to destination j
- d_{ib} is the barrier number b for person i
- p_{ijb}: is the probability that person i face barrier b going to destination j
- β is a weighting parameter

Using the definition of accessibility in (2) has the main limitation for our application that great difficulties for persons to travel, that is, d equal or close to zero, has a relatively small impact on the accessibility measure. By formulating a multiplicative accessibility instead of an additive, this is changed. We define the accessibility as the probability that a journey is undertaken as:

$$A_{ij} = \prod_b (1 - p_{jb}\phi_i(d_b)) \quad (3)$$

Using this definition, we can model the measured accessibility as:

$$A_{ij}^m = \prod_b (1 - p_{jb}\psi_i(d_b)) \quad (4)$$

where

- A_{ij} is the accessibility of person i with regard to destination j
- d_b*:* barrier number b.
- p_{jb}: the probability to face barrier b going to destination j

We can write the measured accessibility for a group of travelers as:

$$A_j^m = \sum_i \hat{p}_{ij} \prod_b (1 - p_{jb} \psi_i (d_b)) \qquad (5)$$

where $\hat{p}_{ij}$ is the probability that person *i* is going for destination *j*.

6. Simulation

We can imagine a situation with twenty identified barriers as described above. They could be difficulty booking the travel on the internet; problem accessing the rail coach; limited ability to read signs etc. In order to assess our measurement model and its associated uncertainty, we simulate the situation with twenty barriers and a selected group of travelers formed by a selection process. For each person in this group, we thus simulate a measurement of each barrier, Ψ_{ib}. These values are randomly distributed values to the barriers for each traveler. Hence, we assign different distributions to the different barriers among the group of travelers. In our simulations, we have chosen three barriers with a normal distribution, 5 barriers with uniform distribution, and 12 barriers with Bernoulli distribution.

A Bernoulli distribution represents barriers that may pose large problems for some individuals but no problem for others. An example can be reading signs which is no problem for the majority but a major problem for persons with a visual impairment. Examples of barriers which have normal or uniform distributions can be for example, narrow passages.

Based on the simulation setup, we can perform several realizations, thus obtaining many results of the accessibility. First we want to identify how large the group of travelers should be in order to be representative for a larger group. We perform simulations with the group size varying from 1 to 200 persons. For each size of the group, we perform 100 trials. Figure 1 shows the standard deviation of the accessibility as a function of number of persons in the group of travelers. The mean value of the accessibility for these simulations is about 0.3. In order to have a standard deviation of a size typically a tenth of the measured value, we need a group of about 40 persons. We will use 40 persons in the following in the paper.

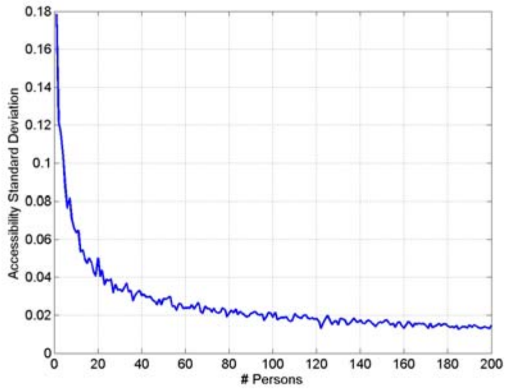

Figure 1. Standard deviation of the accessibility as a function of number of persons

Using simulations, we can also study how the measurement errors propagate through the measurement model. We performed this using Monte Carlo simulations based on 10000 trials. The measurement error is defined as

$$\varepsilon = A_j^m - A_j \tag{6}$$

Figure 2 shows the distribution of the measurement errors for 10000 trials, when the measurement errors are normally distributed. The mean error is 0.010 and the standard deviation is 0.026. The mean value indicates that the measurements are relatively pessimistic. This is due to the cut off of data outside the window [0 1]. In our simulations, we have a majority of measurements close to one, which thus tends to be corrected more often.

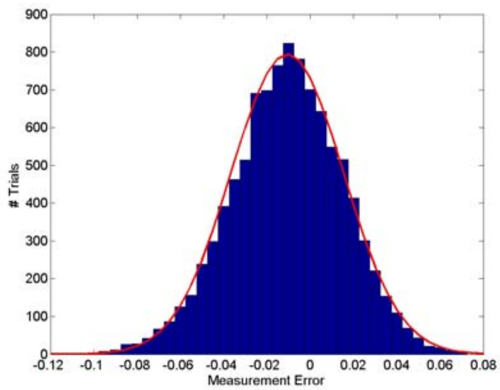

Figure 2. Measurement error distribution based on 10000 trials. The red curve (solid line) shows a Gaussian distribution with the mean and standard deviation from the simulation result

7. Conclusions

In this paper, we suggest a definition of accessibility based on the probability that a journey is undertaken given barriers of different levels of difficulty. By using simulations, we identify how large the group of travelers should be in order to be representative for a larger group. We show that in order to have a standard deviation of the accessibility of a size typically a tenth of the measured value; we need a group of about 40 persons grading the barriers.

Acknowledgments

This work is supported by the Swedish Transport Administration.

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APPENDIX VII

Psychometric measurement and decision-making of Accessibility in public transport for older persons with functional limitations, L. Pendrill, B. Berglund, M. E. Nilsson, C. Sundling, and R. Emardson, intended for Measurement.

Psychometric measurement and decision-making of Accessibility in public transport for older persons with functional limitations

Leslie Pendrill[3]

Birgitta Berglund[1, 2]

Mats Nilsson[1, 2]

Catherine Sundling[1]

Ragne Emardson[3]

1Department of Psychology, Stockholm University, SE-106 91 Stockholm

2Institute of Environmental Medicine, Karolinska Institutet, P.O. Box 210, SE-171 77 Stockholm, Sweden

3Measurement Technology, SP-Technical Research Institute of Sweden, P.O. Box 857, SE-501 15 Borås, Sweden

Abstract

Vulnerable travellers face various challenges in the transport environment which may reduce public travel confidence and consequently lead to decreased mobility. A goal of our research is to find out how to improve the accessibility to railway travelling, especially, for persons with functional limitations, particularly by reducing barriers. A model of the travel situation, identification of quality characteristics and a method of measurement for accessibility have earlier involved (a) the construction of a reference group of representative ‘typical’ older persons from questionnaire data, and (b) the development of an accessibility measure for persons with functional limitations. In this measure, barriers to travel are assigned different weights when encountered by different persons depending on the latter’s functional ability and travel behaviour. The more weight placed on a certain barrier, the less accessible and thus less probable that a particular journey will take place.

These travel barrier weights are analysed psychometrically in the present work based on the replies to questions about ease or difficulty of accessing travel with various barriers (ergonomic, informational, etc) from a randomized sample of 1000 older persons with a range of functional limitations. An invariant measure theory approach (Rasch) is employed which allows (i) transformation of ordinal questionnaire data onto a quantitative interval scale; and (ii) separate measures of barrier level of challenge and person ability. Correlations between perceived accessibility and functional ability and between person ability and functional ability are investigated. Independent sources of measurement uncertainty, such as under-estimation of scores, are distinguished from separate estimates of task challenge and individual travel ability, and accounted for in estimates of reliability of the various measures. Finally, procedures for making decisions of conformity to specifications about rail system and person ability are introduced.

1 Introduction

Sweden has an ageing population, just like the rest of the Western world. The greatest increase in the population is expected to occur among persons over 65, from 17% today to almost 25% in 2030. As people are also expected to live longer and keep an active lifestyle longer in life, the proportion of journeys made by the elderly is expected to increase in the future. At the same time, functional limitations become more common with age and many older persons have more than one functional limitation. So far, the knowledge of older persons' travel behaviour and specific travel needs is limited in Sweden but as every fourth person in Sweden will be 65 or older, the transport system must be built to meet the special needs of this group.

The goal of this research is to develop a methodology to investigate older persons' experiences of and attitudes towards accessibility in public transport, their actual travel behaviour and functional limitations. We also wanted to study whether the degree or sort of functional limitation perceived, influenced accessibility and travel behaviour [Berglund *et al.* [2014]].

The responses to a questionnaire of a randomized sample of 1000 older persons with a range of functional limitations are analysed psychometrically in the present work based on the replies to questions about ease or difficulty of accessing travel with various barriers (ergonomic, informational, etc). An invariant measure theory approach (Rasch) is employed which allows (i) transformation of ordinal questionnaire data onto a quantitative interval scale; and (ii) separate measures of barrier level of challenge and person ability.

2 Method

2.1 Sample and procedure

A questionnaire was sent out in November 2011 to a randomized sample of 1000 older persons (65 - 85 years old) living in the county of Stockholm, Sweden (population approximately 2 000 000). After three months, 574 questionnaires had been returned corresponding to a response rate of 57%. The questionnaires were coded and analysed [Berglund *et al.* [2014]].

2.2 Questionnaire

The questionnaire consisted of questions used in recent Swedish surveys as well as questions developed specifically for the present study. It contained standard *demographic questions* such as age, gender and housing and a section regarding *functional limitations*, use of handicap aids and mobility service (Sw 'färdtjänst'). The main part of the questionnaire focused on *accessibility* in the public transport environment in general and especially in the railway environment, including past experiences and expectations for future travelling. Another part concerned *travel behaviour*. The last part of the questionnaire regarded *travel motivation* and *comfort.*

2.3 Measures

2.3.1. Functional limitations

Two functional limitations severity scales were constructed. One included questions with self-rated functional ability and the other included authority evaluated handicap needs such as mobility service and handicapped parking permit.

2.3.2. Accessibility

The main part of the questionnaire intended to measure *perceived accessibility*. Subsections were: public transport, train journeys in general and long-distance train journeys.

3 Results

We firstly recall the main summary of our initial analysis of the questionnaire [Berglund *et al.* [2014]]. 54% of the respondents were **women** and 46% **men**. The **mean age** was 73 years (SD=5,8).

3.1. Functional limitations

In Table 1, participants' rating of their **health** as compared to others of the same age, shows that most participants rated their health as good or very good (67%). Similarly, most of them (57%) reported having no reduction in their **functional ability –** 58% of the women and 56% of the men. 27% of the repondents rated their functional ability as ”very reduced” or ”extremely reduced”.

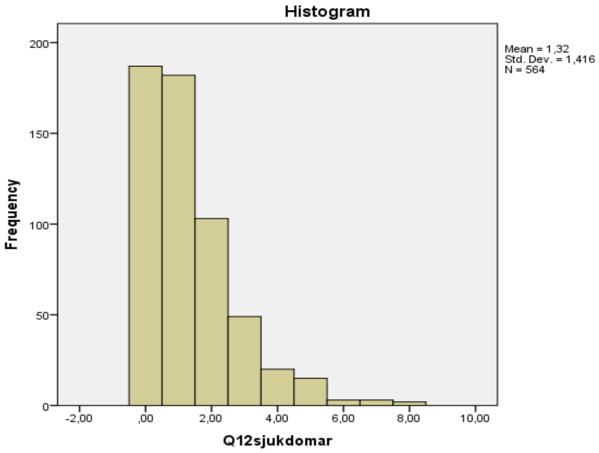
The most common **functional limitation** was vision impairment (22%), hearing impairment (21%) and cardiovascular disease (19%). **Correlations between different functional**

Table 1
Health and function- related sample descriptives

Descriptive	%
Health[1]	
Good or very good	67
Reasonable	28
Poor or very poor	5
Functional ability[2]	
Not reduced ability	57
Reduced ability	43
Assistive aids	
Glasses or lenses	75
Hearing aid	13
Walking frame, wheelchair or crutches	8

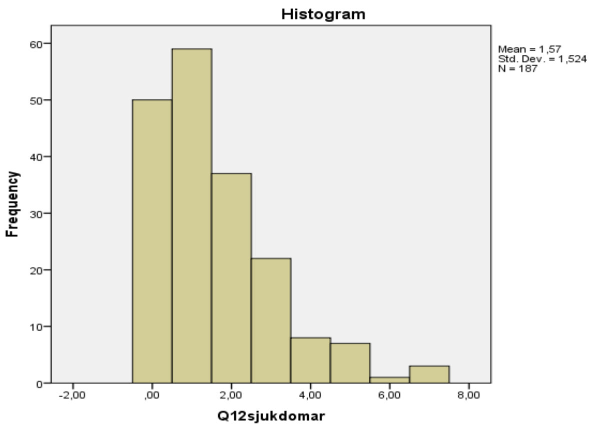
33% of the participants reported having no functional limitation or disease. Of those who reported having **one or more diseases or functional limitations** (Figure 3), 32% had one, while 34% reported having two or more. Most of them (18%) had two, 8% had three and 4% had four. Eight was the highest number of reported diseases or functional limitations. Younger participants had fewer simultaneous functional limitations/diseases than older participants. A majority of the younger (74 years and below), reported no functional limitation/disease or only one, while two or more limitations were more common among the older.

1 Rated on a five-point scale ranging from very good to very poor.
2 Rated on a five-point scale ranging from not reduced to very much reduced.



[redacted]

Figure 3 Number of functional limitations/diseases per participant, all participants



[redacted]

Figure 4 Number of functional limitations/diseases per participant, older participants (75-85 years old)

Figure 4, shows that among the older participants, 26% have reported no functional limitations/diseases, compared to 33% in the group as a whole and the most common answer is one. 41% report having two or more functional limitations/diseases compared to 34% in the group as a whole. There was no statistically significant difference between men and women

8% had been assessed by the local authority to be in need of mobility service (sw ”färdtjänst”, a taxi service for persons with functional limitations). 3% had a handicapped parking permit.

3.3 Accessibility

Overall accessibility in train travelling was considered by 55% to be very good or fairly good. 9% rated accessibility as very poor or rather poor and 29% in between. Respondents without reduced functional ability rated accessibility slightly higher; 62% rated overall accessibility in train travelling as very good or fairly good compared to respondents with reduced functional ability, 56%. Among the respondents with lowest functional ability, nobody rated accessibility as good – most of them (67%) rated accessibility as extremely poor. Logistic regression showed that age, gender, income and car possession did not predict perceived overall accessibility.

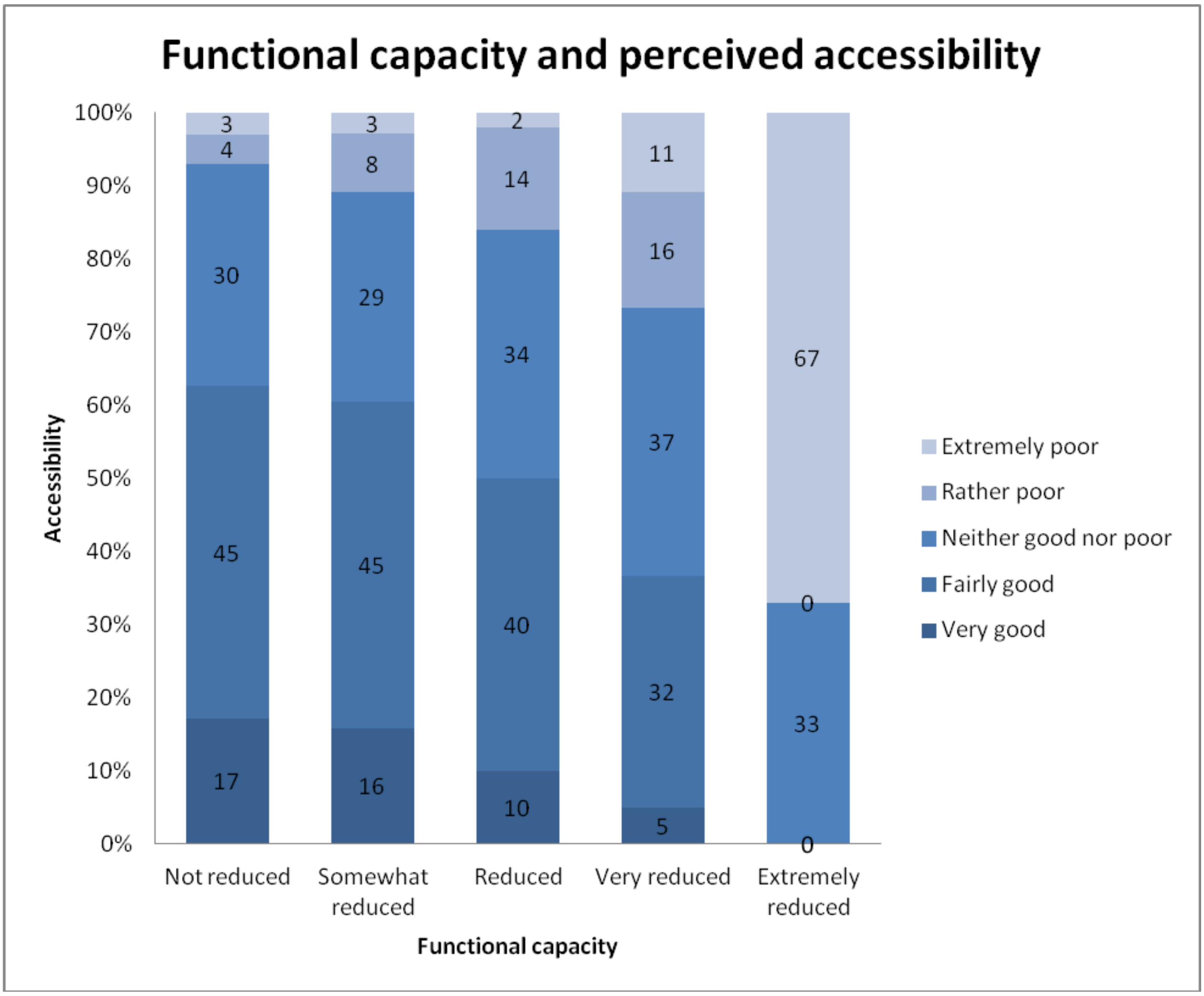


Figure 5. functional ability and perceived accessibility.

Examples of barriers encountered in train travelling were delays, long waiting times and other **time aspects** including too early departures, stressful changes between means and trains starting before passengers have taken their seats. 44% of the participants with **mobility service** perceived **overall accessibility** as neither good nor bad (Figure 6). 30% found it very good or fairly good and 14% extremely poor or rather poor.

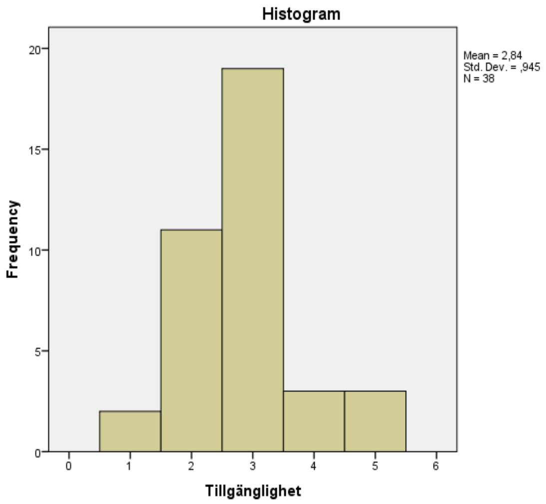


Figure 6. Participants with mobility service. Perception of overall accessibility in train travelling.

One section of the questionnaire concerned accessibility during different parts of the latest long-distance train journey, from the planning of the trip until reaching the destination. The participants were asked to rate how **easy or difficult it was to use the travel environment.** Most of the respondents found travelling easy. Taken together, the mean percentage of respondents perceiving the travel environment as ”easy” or ”good” was 69% while the number for those who thought it was ”difficult” or ”bad” was 7%.

3.3.1 Informational barriers

Regarding **information during planning of the trip**, 73% thought it was easy (very easy or relatively easy) to get information. Complaints concerned for example difficulties understanding the ticket system. Also, most respondents (74%) thought it was easy to to **buy tickets** but a long wait for ticket purchase or too few choices regarding seat reservations or credit cards accepted were examples of complaints. Perceived difficulties concerned information and orientation (for example signposting), and long distances within the station. 66% found it easy to take part of **information at the stations**. The **13%** who did not find it easy, wanted more staff or visual information. There were also complaints about unsystematic information or broken signs. **Orientation within stations areas** was easy according to 64%. **11%** found it difficult because of inadequate information and because of ongoing reconstruction.

Information onboard the train was perceived as good by 62% compared to the 73% who regarded information as good during the planning stage. Loudspeakers were the main cause of discontent, being difficult to hear, too loud or not functioning.

Finally, **personal service from staff** during the journey was judged to be good by 68% and only 4% found it unsatisfactory, mainly because of absence of staff.

3.3.2 Ergonomic barriers

69% found it easy to **move within the station area(s)** but 10% found it relatively difficult or very difficult. Most respondents (74%) also found it easy to **get on the train.** Difficulties mainly concerned climbing the high steps into the train with luggage.

To move around **inside the vehicle** was perceived as easy by 72%. Complaints concerned mainly insufficient stability, in the train; vibrations, lurching etc. The **lavatory** was easy to use and/or to get to according to 65% but some respondents had experienced lavatories that were closed, dirty, out-of-service or lumbered of luggage. **Getting off the train** was easy according to 79%. Again, luggage and also high steps were barriers mentioned as well as unhelpful staff.

4 Specification of aims, system, construct, quality characteristics and metrics

As with measurements of all kinds which are made not for their own sake but as a basis for essential decisions, for instance, about the conformity of product to specifications, the validity and reliability of the measurements have to be ensured from the start[3]. This involves, particularly for subjective measurements, a correct and proactive definition of the aim [§4.1]; system (user, product, task, environment) subject to assessment [§4.2]; the identification of key quality characteristics of the system [§4.3]; and the setting of specification limits for each such characteristic. Thereafter, a measurement system fit for the task at hand should be developed and subject to all the steps of conformity assessment. Finally, decisions of conformity can then be made of whether the aims are satisfied or not [§5.4].

Examples of earlier research in this area include that of a Swedish research team[4] which developed a supportive instrument, “The Travel Chain Enabler”, for assessing urban public bus transportation accessibility for persons with functional limitations.

4.1 Aims

The overall aim ultimately [Figure 4.1] is to provide the ‘market’, i.e. society, with improved ‘services’ of more accessible rail travel, by mustering available ‘capital’ – in terms of rail system products & infrastructure together with persons’ functional abilities:

[3] K E Roach 2006 ”Measurement of Health Outcomes: Reliability, Validity and Responsiveness”, *JPO* **18**, p8

[4] Iwarsson, S, Jensen G and Ståhl A 2000 Travel chain enabler: Development of a pilot instrument for assessment of urban public bus transport accessibility *Technology and Disability* **12** 3-12; Jensen S, Iwarsson S, and Ståhl A 2002 Theoretical understanding and methodological challenges in accessibility assessments, focusing the environmental component: an example from travel chains in urban public bus transport *Disability and Rehabilitation* **24**(5) 231-24

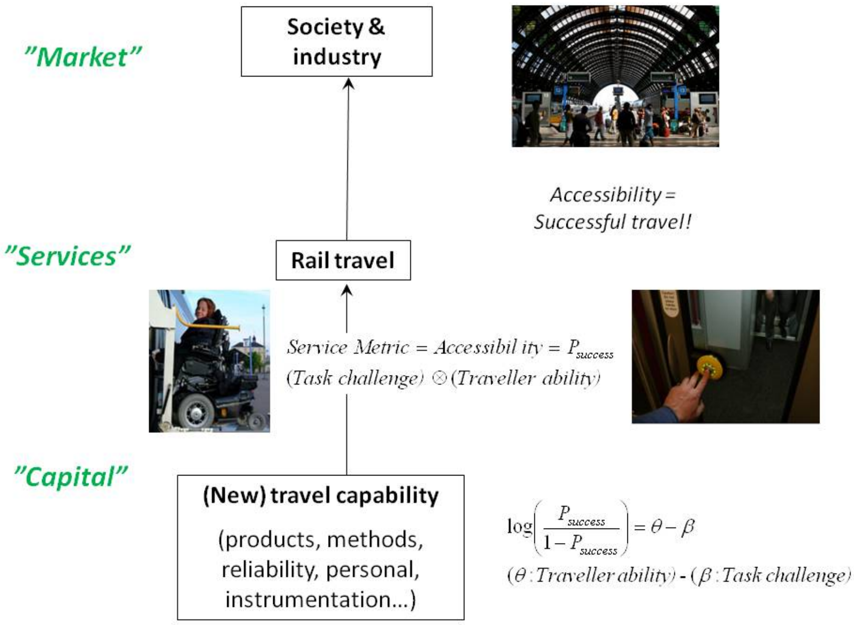


Figure 4.1 Accessibility = successful service of providing better rail travel

4.2 System and Construct

The construct of interest is the overall accessibility of the rail system as perceived by travellers with functional limitations. That accessibility can be modelled as being determined by an aggregate of the pairwise, mutual interactions between the three principal elements of the studied system [Figure 4.2], namely: (i) the traveller; (ii) the rail system; and (iii) the tasks necessary for travel. These interactions are functions of the intrinsic attributes of each of these system elements (e.g. person ability, task challenge, product quality, etc) but can also be influenced by the overall environment.

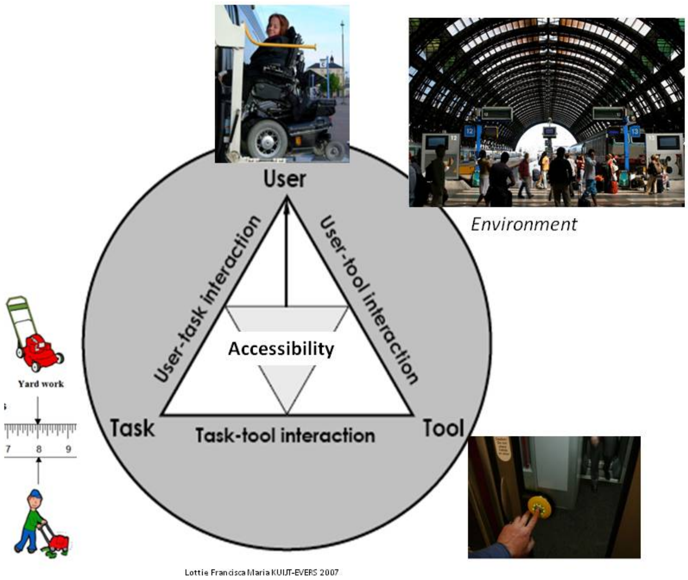


Figure 4.2 System and construct

4.3 Quality characteristics and metrics

In the present studies, amongst the various components of the system studied [Figure 4.2], two particular parameters – travel task and traveller ability - are systematically varied, while the others (e.g environment, etc) are kept as constant as possible.

An overall model [Emardson *et al.* (2011)] for the aggregate accessibility (A_{ij}) for a person (i) making a complete journey (j) – from the initial planning, through travel, until arriving at the final destination – is:

$$A_{ij}^{m} = \prod_{b} \left[1 - p_{jb}\psi_i(d_b)\right] \quad (4.1)$$

as a product over the series of barriers (b) that have to be overcome during the journey, of the individual person's perceived effort, ψ_i, when facing a certain barrier d_b, together with probability, p_{jb}, that a person will face that barrier.

The measured perceived effort, ψ_i, will be a function of the true value, ϕ, and an error component ν.

$$\psi_i(d_b) = f\left(\phi_i(d_b), \nu_{ib}\right) \quad (4.2)$$

The true value, ϕ, of the perceived effort is a function for each person i and barrier d. In principle, the function might be different for different barriers and different people. The true value is of course impossible to know, but its existence can still be assumed. A linear measurement model can be adopted so that the relation between the measured perceived effort for each barrier and the true value can be written as:

$$\psi_i(d_b) = \phi_i(d_b) + \nu_{ib} \quad (4.3)$$

The error component ν is a random variable which we assume is Normally distributed with a mean value υ and variance, σ^2_ν.

The perceived effort function ϕ is defined between 0 and 100%, and can be converted into an accessibility score

$$P_{success} = 100\% - \phi \quad (4.4)$$

of how successful deployment of the system is for each task at hand (the service of providing good rail travel [Figure 4.1]). Thus the function value ϕ =100% indicates a barrier such that the probability of cancelling the journey is 100% when facing such a barrier. A value of 0 indicates the opposite, i.e., the barrier causes no problem to the traveller and the accessibility is complete, i.e. $P_{success}$ = 100%.

In the present work, we will model the accessibility score when negotiating a barrier as a product, in some way, of task challenge and traveller ability:

$$Service\ Metric = Accessibility = P_{success} = (Task\ challenge) \otimes (Traveller\ ability) \quad (4.5)$$

Understanding how perceived effort when travelling depends on the intrinsic challenge posed by the various barriers encountered, preferably independently of abilities or attitudes of particular persons studied, will enable future predictions of travel accessibility for other people as well the identification of which barriers limit accessibility the most and which should be improved. As will be discussed below, this also opens up the possibility of establishing metrological standards for accessibility [§5.3.1].

Understanding how perceived effort when travelling depends on the intrinsic ability of each individual, preferably independently of levels of challenge posed by specific barriers, will give opportunities to perhaps train people how to negotiate barriers better, and to identify what aspects of barrier challenge relate to human perception, so these challenges can be reduced.

A typical requirement (common to Generalised linear models and Logistic regression) is that the accessibility $P_{success}$ should preferably exceed 50% as a target specification limit.

5 Separate estimates of barrier challenge and traveller ability

To benefit fully from the information contained in perceived accessibility observations, it is essential to make separate estimates of person and item attributes. In measuring and analysing accessibility, according to the discussion in §4.3, it is conceivable that one could model the task:traveller interaction as some kind of arithmetic product, as indicated schematically in eq. (4.5). But, to deal with the intrinsic nature of the perceived accessibility, we chose instead a classical logistic regression approach[5] to qualitative data, where the log-odds of success are modelled as linearly varying with a difference in a traveller attribute ('ability') and a task attribute ("level of challenge"):

$$\log\left(\frac{P_{success}}{1-P_{success}}\right) = \theta - \beta = (\theta : Traveller\ ability) - (\beta : Task\ challenge) \quad (5.1)$$

One could also have included additional attributes for other system elements important for accessibility, e.g. train system 'quality', how easily a product can facilitate accessibility or provide 'satisfaction', for instance.

The attribute values transformed from the ordinal raw scores, via eq. (5.1), lie on a quantitative scale on which all of the usual statistical and metrological tools can be applied (in contrast to ordinal scales – see Annex). The approach allows one to reveal explicitly typical ordinal scoring errors common in responses for the raw data not linear across the range[6] [Figure 5.3]. Systematic investigation of eq 5.1 can be made for a fixed person attribute, θ, for a range of item attributes, β, or vice versa, and similarly for the other system components, as required.

A significant advantage of this Rasch, invariant measure theory approach, is that it provides measures of service not affected by:

[5] H Theil 1970, "On the estimation of relationships involving qualitative variables", *American Journal of Sociology*, **76**:103–154

[6] R W Massof 2005 "Applications of stochastic measurement models to visual function rating scale questionnaires", *Opthalmic Epidemiology*, **12**, 1 – 22, doi: 10.1080/09286580590932789

- the abilities or attitudes of particular persons measured
- the difficulties of particular survey or test items used to measure[7].

Table 5.1 Summary of data analysis methods

Data analysis method	Description	Benefits	Drawbacks
Rasch Product or task attribute, β, and person attribute, θ (Tezza *et al.* 2011[8], Wright 1994)	For each participant and characteristic calculate from the data estimates of Product attribute, β, and person attribute, θ, based on logistic regression.	Clear separation of product and person variations. Transforms ordinal data onto a quantitative scale	Requires advanced, but commercially available software
Rasch Percentages, $P_{success}$ (Linacre 2002, Wright 1994[9])	For each participant and characteristic calculate the result in terms of percentage of an optimal result. Then calculate an average for each person and an overall average for all participants.	Simple. Possible to incorporate the weights. Simple to interpret the results	Quantifications of optimal results are needed.

Rimmer *et al*. [2004][10] developed the AIMFREE set of psychometric measuring instruments for persons with functional limitations. They developed and validated 16 survey instruments that measured accessibility to recreational and fitness environments. Interestingly, they utilized the Rasch model for demonstrating good psychometric properties of their instrument.

The Rasch model [eq. (5.1)] has been connected to the Shannon entropy, *H*, in communicating information about a binary observation through the relation[11]:

$$H(P_{success}) = -\left[P_{success} \cdot \log(P_{success}) + (1-P_{success}) \cdot \log(1-P_{success})\right] = \int -z \cdot dP_{success} \qquad (5.2)$$

where $z = \log\left[\frac{P_{success}}{1-P_{success}}\right] = \theta - \beta$, the Rasch psychometric log-odds, is the explanatory variable in Generalised Linear models behind the success in rail accessibility in the present study. One can

[7]W P Fisher, Jr., 1997 ”Physical Disability Construct Convergence Across Instruments: Towards a Universal Metric”, *Journal of Outcome Measurement*, **1**(2), pp 87 - 113

[8] R Tezza, AC Bornia, DF de Andrade 2011, ”Measuring web accessibility using item response theory: Principles, features and opportunities”, *Interacting with Computers* **23**, 167 - 75

[9] B D Wright, ”Comparing factor analysis and Rasch measurement”, *Rasch Measurement Transactions*, **8**:1, p. 350, http://www.rasch.org/rmt/rmt81r.htm

[10]Rimmer J H, Riley B, Wang E and Rauworth A 2004 Development and validation of AIMFREE: Accessibility instruments measuring fitness and recreation environments, *Disability and Rehabilitation* **26**(18) 1087-1095

[11] Linacre J M 2006 “Bernoulli Trials, Fisher Information; Shannon Information and Rasch”, *Rasch Measurement Transactions* **20**(3) 1062-1063; L R Pendrill and W P Fisher Jr., 2014

regard $P_{success}$ as a measure of the dissimilarity ("psychometric function"), that is, the probability of judging that one stimulus is greater than another. The integral of z in eq. (5.2) corresponds to estimating the subjective distance, $D(a,b)$ between two perceived stimuli (a,b) by cumulating the psychometric function between the adjacent stimuli in so-called Fechnian scaling[12],[13].
For the accessibility analyses the following nomenclature applies:

$$i = \begin{cases} 1, test\ person\ A \\ 2, test\ person\ B \\ 3, test\ person\ C \\ \quad \ldots \end{cases} \quad j = \begin{cases} 1, barrier\ a \\ 2, barrier\ b \\ 3, barrier\ c \\ \quad \ldots \end{cases} \quad k = \begin{cases} 1, question\ Q1 \\ 2, question\ Q2 \\ 3, question\ Q3 \\ \quad \ldots \end{cases}$$

In the case of classification into more than two (k = 1, …, K) categories, the polytomous[14] Rasch probability of response $q_{i,j}$ of person i to item j is given by:

$$q_{i,j,k,c} = \frac{e^{\left[c\cdot(\theta_i - \beta_j) - \sum_{k=1}^{c} \tau_k\right]}}{1 + e^{\left[\sum_{k=1}^{K} k\cdot(\theta_i - \beta_j) - \sum_{c=1}^{k} \tau_c\right]}} \qquad (5.3)$$

where τ_k denotes the threshold for the k^{th} category.

5.2 Results Rasch analysis

Fits of the data for a given product to the Rasch formula [5.3] produce values transformed to the quantitative person attributes, θ, and item attributes, β. In Figures 5.1 are shown examples of Rasch curves fitted for the responses of 162 travellers (those test persons of the total 1000 who responded to most questions), together with the scoring data specific to two questions: *Q42* and *Q44* which for these are found to lie at opposite ends of the classification scale for accessibility.

Measure (raw data) per question: $v_{i,j,k} = Score(1,\ldots,6)$

The regression behind each of these fits[15] is a least-squares adjustment of the residuals between the observed and expected scores:

$$\Delta v_{i,j} = v_{i,j} - v'_{i,j} \qquad (5.4)$$

---

[12] Dzhafarov E N 2012 Chapter 9 in Berglund B, Rossi G B, Townsend J, Pendrill L R 2011 *Theory and methods of measurements with persons* (New York: Taylor & Francis)

[13] L R Pendrill and W P Fisher Jr., 2014, "Quantifying Human Response: Linking metrological and psychometric characterisations of Man as a Measurement Instrument" ", *Measurement*, (submitted March)

[14] D Andrich 1978, "A rating formulation for ordered response categories", *Psychometrika*, **43**, 561-73; G.N. Masters 1982, "A Rasch model for partial credit scoring" *Psychometrika*, **47**, 149-174

[15] WINSTEPS, http://www.winsteps.com/index.htm

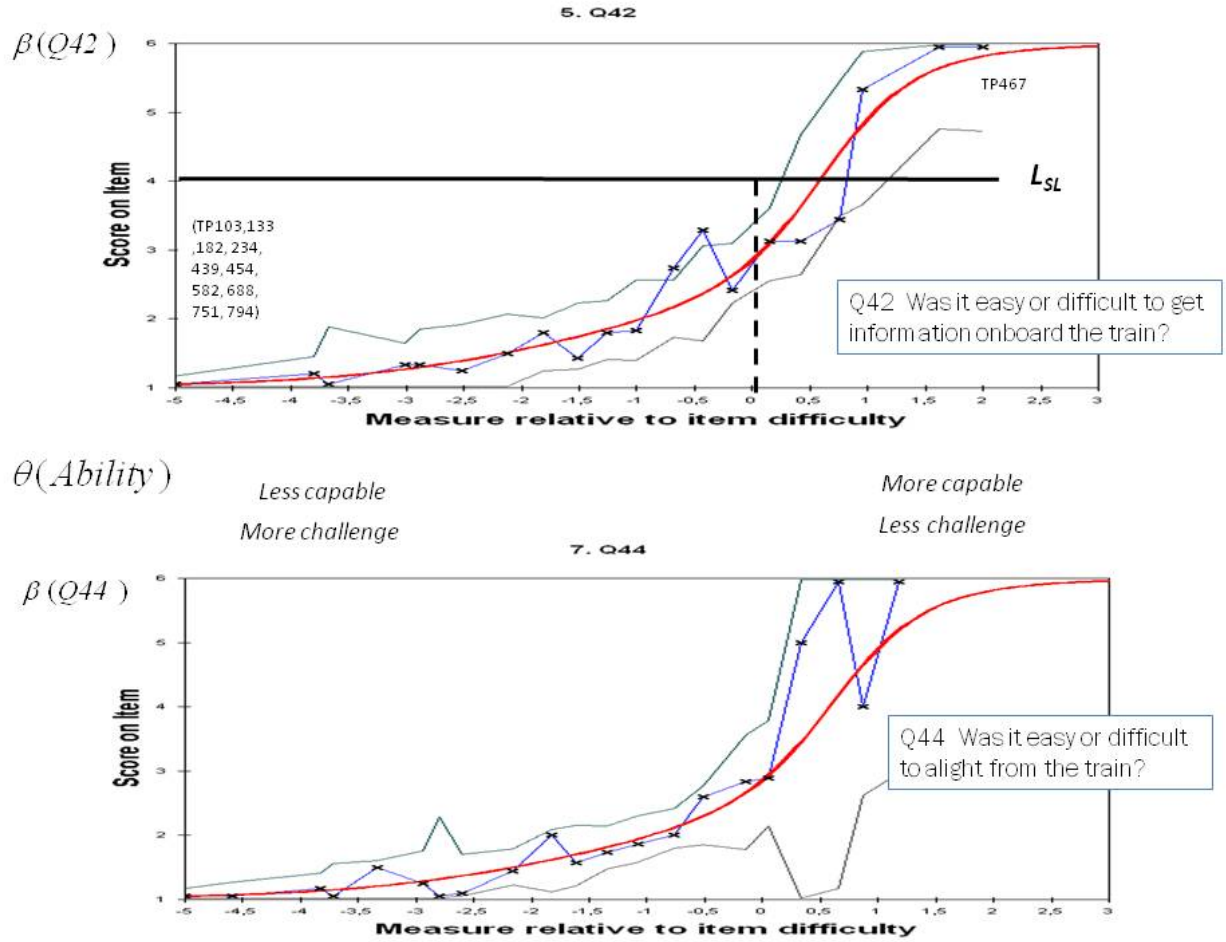


Figure 5.1 Rasch curves: Examples of responses of elderly (test persons) for two questions: Q42 and Q44

$P_{success}$ = 50% at the point where the person attribute, θ_i, equals the item attribute, β_j.

For each fit, the Rasch analysis gives separate estimates of the 162 individual person attributes, θ_i, and 10 question item attributes, β_j, as shown in the histograms of Figure 5.2.

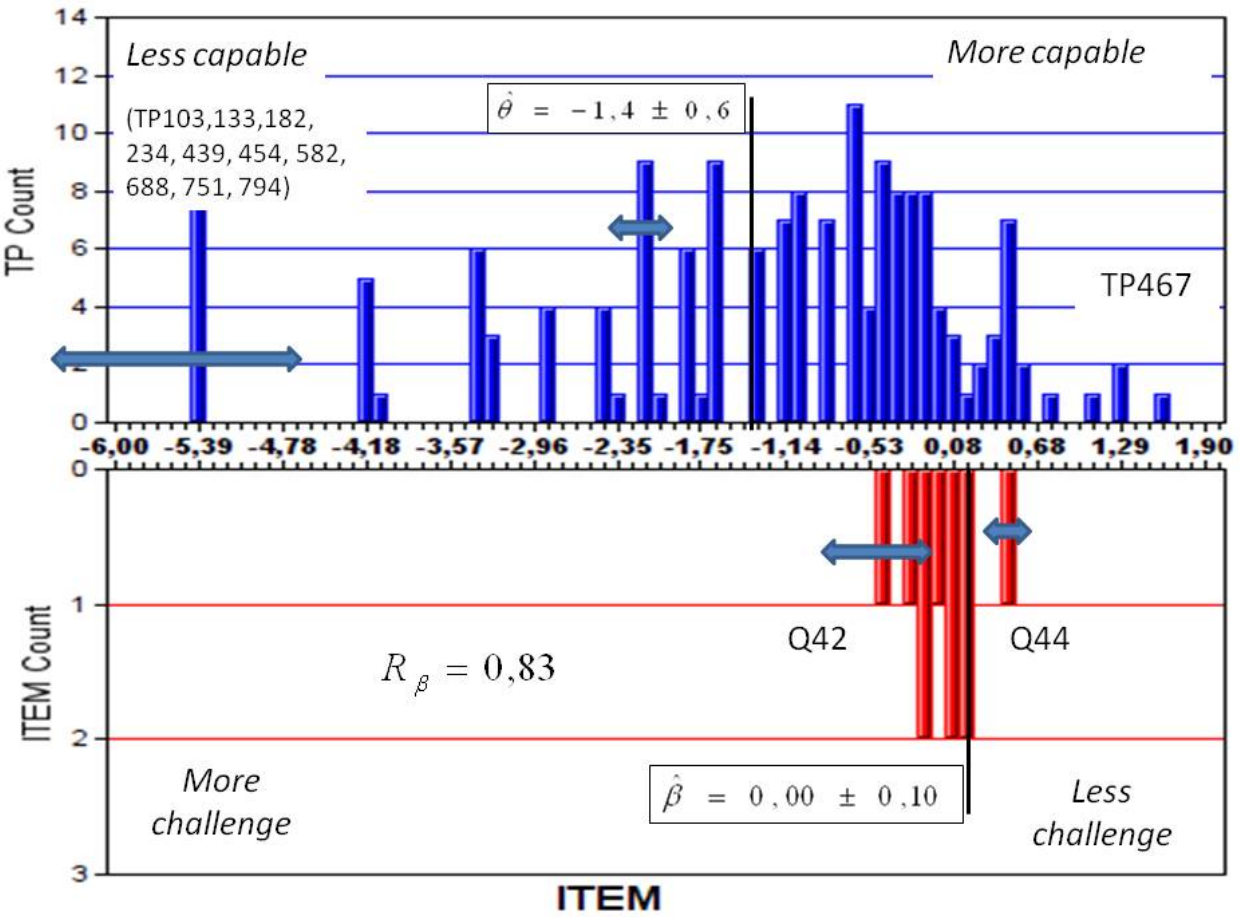


Figure 5.2 Rasch histograms for test persons' capability and barrier challenge

Apparent from such plots are the location and dispersion of the person attributes and item attributes. For instance, the **blue** individual person attribute values indicate a considerable spread, skewed away from the corresponding distribution of the measured item attributes (**red** columns) and heavily towards reduced capabilities, perhaps reflecting the functional limitations of the people studied. Broadly speaking, questions concerning ergonomics [such as Q44, §3.3.2] appear on the average to indicate less challenge than questions addressing informational (or cognitive) barriers [such as Q42, §3.3.1].

As a guide to improving future studies, the apparent considerable mismatch between person attributes and item attributes evident in Figure 5.2 could be reduced – thereby leading to better reliability – by posing additional questions of a more challenging nature.

5.3 Measurement reliability, measurement uncertainty and metrological traceability

No decisions about the significance of any apparent differences in different measures can be made without demonstrating sufficient measurement reliability and metrological traceability.

5.3.1 Metrological traceability

In general, the measured β differs, because of limited reliability, from the 'true' β', with an error ε_β:

$\beta = \beta' + \varepsilon_\beta$

Invariant measure theory, allowing the level challenge β for a particular task (such as presented by a barrier to travel) to be estimated independently of who is encountering the challenge, permits the identification of a metrological standard for barrier challenge. Once an agreed definition and realisation of the standard barrier has been achieved it can then be used reproducibly as a reference in other travel situations. As in traditional metrology, this traceability enables all the advantages commensurate with objectively comparable measurement.

For instance, having access to a psychometric barrier challenge standard would allow an estimate of each person's ability θ to access travel for a range of barriers of different challenge to be metrologically calibrated by measuring a task of known challenge. This procedure determines the measurement error ε_θ in person ability: $\theta = \theta' + \varepsilon_\theta$

Inserting the corrected item β and person θ attribute values in the Rasch expression [eq. 5.1] allows a more correct estimate of the accessibility score, $P_{success}$, which in turn allows correction of the perceived effort function $\psi_i(d_b) - \mu_{ib}$ [as given by eq. 4.4] . Finally, the overall accessibility for a complete journey, correctly calibrated would be obtained as:

$$A_{ij}^{m} = \prod_{b} \left[1 - p_{jb}\left(\psi_i(d_b) - \mu_{ib}\right)\right] \qquad (5.5)$$

5.3.2 Incorrect scoring

The Rasch analysis can reveal explicitly typical ordinal scoring errors common in responses for the raw data not linear across the range [Massof]. As shown in Figure 5.3, a plot of the Rasch β_j against the corresponding simple average, $\bar{v}_{j,k} = \frac{1}{N_{TP}} \cdot \sum_{i=1}^{N_{TP}} v_{i,j,k}$, of the raw score data $v_{i,j,k} = Score(1,...,7)$ shows little evidence in the present case that the travellers tend to score incorrectly. Such incorrect scoring is often observed towards the extreme ends of the Likert scale, whereas the averages of the present scores to each question are mostly mid-range, where the perceptive scale is approximately linear.

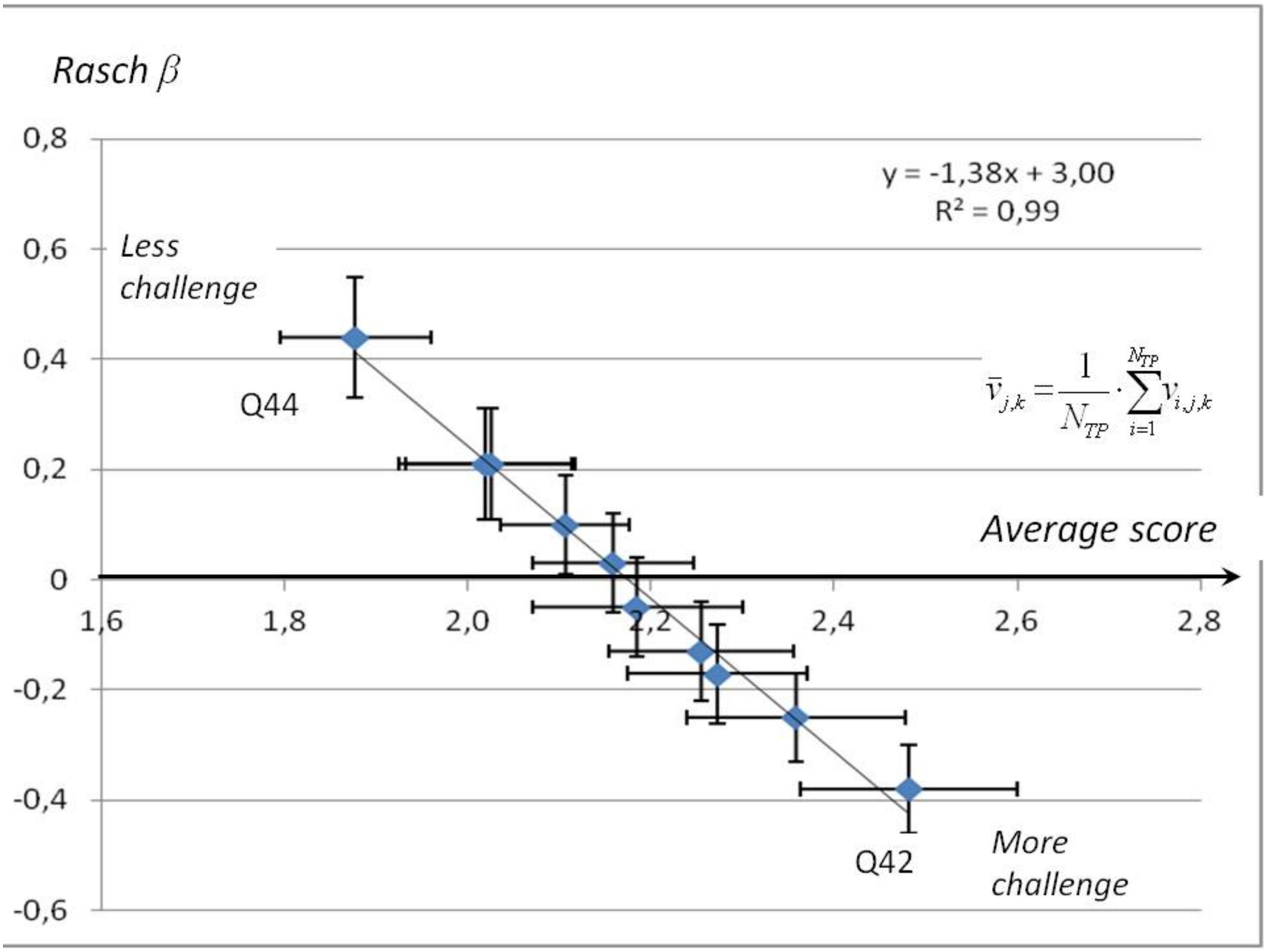


Figure 5.3 Test of Incorrect scoring

On the contrary, several of the individual person scores – particularly those at one extreme of each question Likert scale – are strongly under-estimated and, as shown in Figure 5.2, the uncertainties are particularly large for TP103,133,182, 234, 439, 454, 582, 688, 751, 794 at the low-score, low-capability end of the scale.

5.3.3 Reliability

Measurement reliability, according to [Roach 2006][16], is a gauge of whether an outcome measure produces the same number each time a measurement instrument is administered. There are several aspects to reliability:

Self-reporting: Test-Retest reliability e.g. limited by wording & interpretation

The Rasch analysis has not revealed significant differences in raw scoring related to interpretation (Figure 5.3)

Internal consistency: Do all items in the outcome measure address the same underlying concept?

A relatively low consistency is found amongst the different person attributes (Figure 5.2). A first-order assumption is that a single item parameter, β, is the principal component for all the items. A multivariate, principal component analysis which tests this assumption is made below [§5.3.7].

[16] K E Roach 2006 "Measurement of Health Outcomes: Reliability, Validity and Responsiveness", *JPO* **18**, p8

A gauge of measurement uncertainty is expressed as a standard error $SE(\theta_i, \beta_j) = \sqrt{\frac{1}{\hat{P}_{i,j} \cdot (1 - \hat{P}_{i,j})}}$, for instance product j:

$$u(\varepsilon_\beta)_{all;j} = realSE(\beta)_{all;j} = \frac{1}{\sqrt{\sum_{i=1}^{TP}\left[\sum_{k=1}^{K} k^2 \cdot q_{i,j,k} - v^2{}_{i,j}\right]}} \quad (5.6).$$

The measurement (standard) uncertainties calculated with these expressions are plotted in the various results graphs in this article.

5.3.4 Precision and trueness; construct alleys

The accuracy of any measurement system contains measures of both precision (dispersion) and trueness (bias). A graphic measure of the accuracy of perceptive measurements is provided by the so-called "construct alley[17]" plots of Rasch β_j against the Infit z-score:

$$Infit\ z\text{-}score = \frac{\Delta v_{i,j,k}}{\sqrt{\left[\sum_{k=1}^{K} k^2 \cdot q_{i,j,k} - v^2{}_{i,j}\right]}} \quad (5.7)$$

where the residual $\Delta v_{i,j} = v_{i,j} - v'_{i,j}$ and the expected score q is given by eq. (5.3).

Such a plot (Figure 5.4) shows a gauge of measurement **precision** along the vertical axis in terms of the individual uncertainty intervals associated with each estimate of Rasch β_j. It also shows a gauge of measurement **trueness** in terms of the spread in the Infit z-score [eq. 5.7], in particular how well each datum fits within the 'construct alley' of two standard deviations about zero.

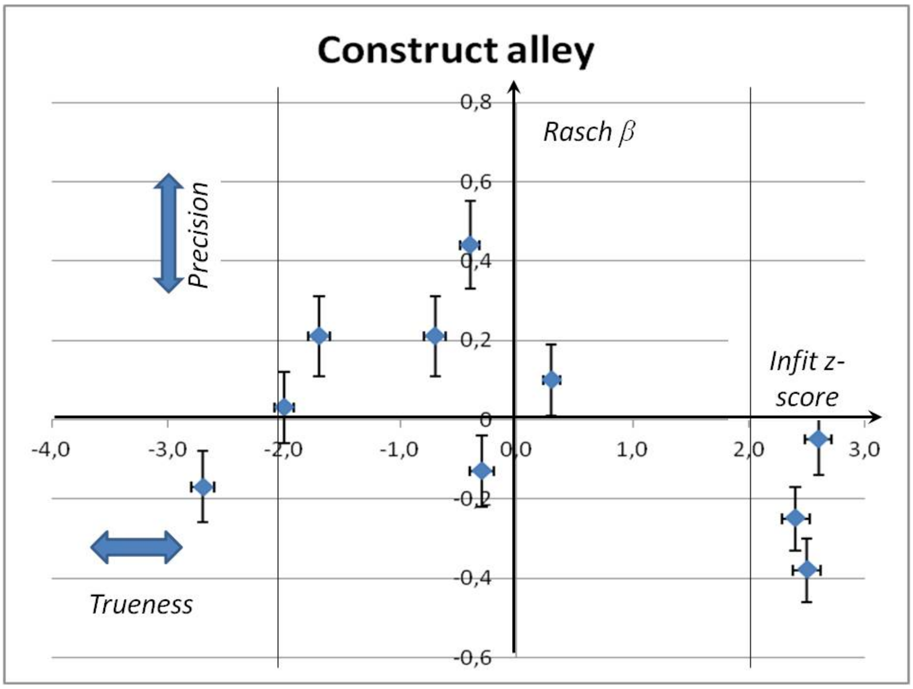


Figure 5.4. Construct alley plot

[17] R W Massof 2005 "Applications of stochastic measurement models to visual function rating scale questionnaires", *Opthalmic Epidemiology*, **12**, 1 – 22, doi: 10.1080/09286580590932789

5.3.5 Multivariate principal component analysis (PCA)

A first-order assumption of a Rasch analysis is that a single item parameter, β, is the principal component for all the items (and similarly for the attributes, θ, of different raters). A multivariate, principal component analysis which tests this assumption is the Rasch "PCA of residuals" which seeks patterns "unexpected" in data which are not in accord with the Rasch measures. The "First factor" (in the traditional Factor Analysis sense) is the Rasch dimension. By default all items (or persons) are in "first factor" (or first PCA component in correlation matrix of residuals) until proven otherwise.

```
|------+-------+-------------------+-----------|
| 1 1 |  .78 |   .21  .88  .88 |A    3 Q40 |
| 1 1 |  .78 |   .44  .92  .81 |B    7 Q44 |
| 1 1 |  .50 |   .21  .74  .72 |C    4 Q41 |
| 1 2 |  .18 |  -.25 1.36 1.49 |D    6 Q43
| 1 2 |  .00 |   .03  .72  .63 |E    1 Q38 |
|      |-------+-------------------+-----------|
| 1 3 | -.42 |  -.38 1.36 1.65 |a    5 Q42 |
| 1 3 | -.36 |   .10 1.04 1.45 |b   10 Q51 |
| 1 3 | -.29 |  -.05 1.44 1.85 |c    9 Q46 |
| 1 3 | -.26 |  -.13  .95 1.16 |d    2 Q39 |
| 1 3 | -.21 |  -.17  .66  .87 |e    8 Q45 |
-----------------------------------------------
```

Figure 5.6 Rasch PCA: Accessibility questions Q38 – Q51.

A first plot [Figure 5.6] shows contrast within data between pairs of sets of items orthogonal to Rasch dimension. Groups of items which share the same patterns of unexpectedness, probably also share a substantive attribute in common, a "secondary dimension" [Linacre 2002].

Table of STANDARDIZED RESIDUAL variance (in Eigenvalue units)

		-- Empirical --		Modeled
Total raw variance in observations =	19.7	100.0%		100.0%
Raw variance explained by measures =	9.7	49.1%		50.4%
Raw variance explained by persons =	6.4	32.6%		33.4%
Raw Variance explained by items =	3.3	16.6%		17.0%
Raw unexplained variance (total) =	10.0	50.9%	100.0%	49.6%
Unexplned variance in 1st contrast =	2.0	10.2%	20.1%	
Unexplned variance in 2nd contrast =	1.7	8.4%	16.5%	
Unexplned variance in 3rd contrast =	1.2	5.9%	11.6%	

Figure 5.7 Rasch PCA variances: Accessibility questions Q38– Q51

From the deduced multivariance analysis [Figure 5.7], one can note:

- Twice as much of the observed raw variance comes from persons rather than from items
- The variance (about 50%) unexplained by the initial Rasch analysis appears to be associated with up to 3 contrasts shown in [Figure 5.6]. Cluster 1 is mainly ergonomically related questions; cluster 3 is mainly informational/cognitive; while cluster 2 is a mix of these two.

5.4 Decisions of conformity and significance testing

5.4.1 Measurement/item separation and conformity decision-making

As in all conformity assessment, it is often a major challenge to separate 'true' intrinsic item variations from apparent dispersion arising from limited measurement quality.

$$separation(\beta) = \frac{trueSD(\beta)}{realSE(\beta)} \tag{5.8}$$

A reliability coefficient for the item attributes is calculated as:

$$R_\beta = \frac{True\ \ variance}{Observed\ variance} = \frac{\mathrm{var}(\beta)}{\mathrm{var}(\beta')} = \frac{\mathrm{var}(\beta') - \mathrm{var}(\varepsilon_\beta)}{\mathrm{var}(\beta')} \tag{5.9}$$

Typical values of R_β in the present investigation, where measurement uncertainty is estimated with the expression (5.9), lie in the region of 0,8 [Figure 5.2] – separation of 3, where about 75% of the observed variation is explained by product variations rather than limited measurement quality - which is considered acceptable [Linacre 2002]. As is well-known, the reliability coefficient is related in part to the number of test persons and the number of items, for instance, via the Spearman-Brown prophecy formula.

In the optimised uncertainty methodology approach, consequence costs of incorrect decisions are balanced against the cost of performing more measurement (e.g. through larger numbers of test persons and/or items). The optimised uncertainty approach has demonstrated that traditional 'rule-of-thumb' limits on reliability are often higher than the optimum uncertainty [Pendrill 2007, 2014] with correspondingly unnecessarily large consequence costs from incorrect decisions of conformity.

5.4.2 Significance tests; radar plots

Radar plots based on Rasch analysis are in the present case comparable with traditional statistical analysis [Figure 5.5].

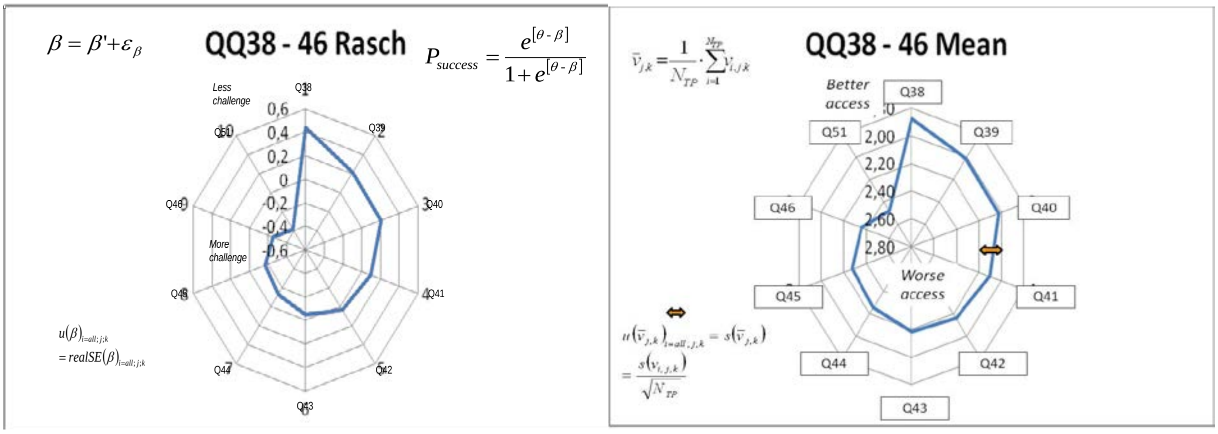


Figure 5.5. Radar plots: Average (right) and Rasch βj (left).

Rasch analysis is in general preferred since it provides (i) less 'noise', since test person variability has been separated out of the data and (ii) correction for scale over-estimation at the high end of rating.

It can be seen from Figures 5.5 that there are significant differences in response to the 10 questions of the survey.

Acknowledgements

Financial support is gratefully acknowledged from the Swedish Transport Administration, the Swedish National Metrology Program, the Swedish Research Council for the Environment (FORMAS) and the Norrbacka-Eugeniastiftelsen in Stockhom, Sweden. The research results of this project will help to achieve a more flexible and independent travel behaviour for all, thus contributing to the Swedish governmental assignment to its Transport Administration.

Annex A Theoretical analysis of ordinal accessibility data

A.1 Analysis of ordinal data

In an analysis of the raw scores obtained with questionnaires and similar instruments often used to measure human response, the type of data obtained presents a number of considerable challenges, associated with ordinal, multidimensional and subjective characteristics.

Two facts together mean that quantitative comparisons of the measurement values derived from raw data are not directly possible:

- For data typically associated with an ordinal scale, it is only known that one measurement value is ordered higher than another, but the exact numerical distance between two data points is not known in general. In such cases, a serious challenge [Svensson 2001][18] is that several of the most common tools of statistics – such as calculation of a mean or standard deviation – employed in usual expression of measurement uncertainty, cannot be unconditionally used to characterise the location and dispersion of qualitative measurements on ordinal scales typical in such measurements.
- Secondly, derived measurement values are not necessarily unidimensional, so that combining individual values may result in a derived value that conceals numerous unrelated dimensions.

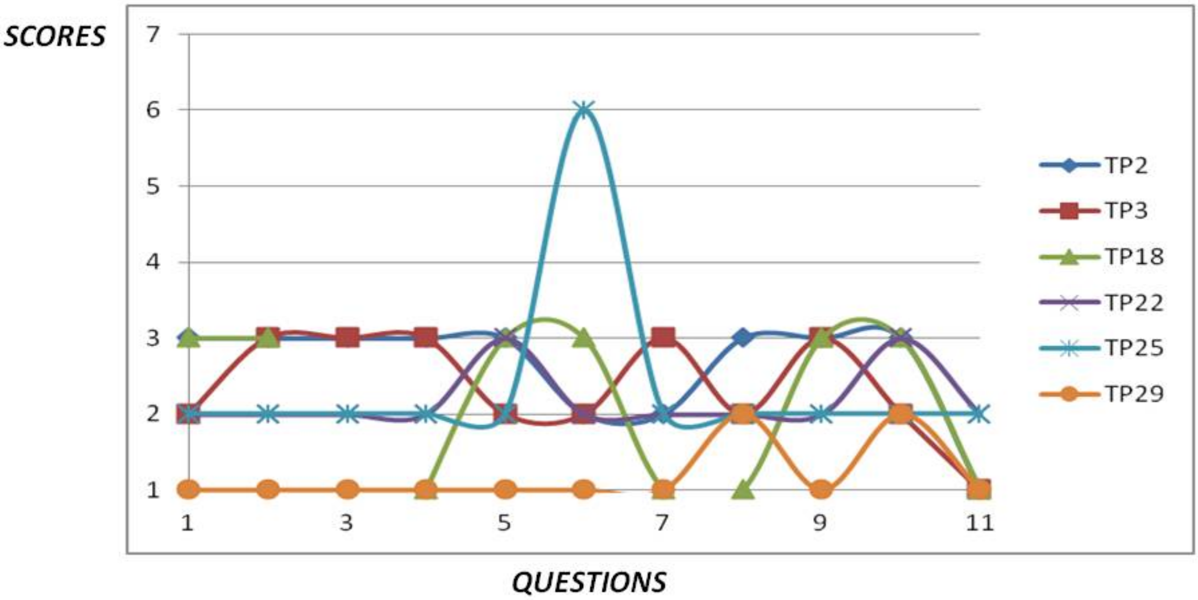
The aim in this Annex is to present an analysis of data taking due account of its ordinal nature. An introductory discussion of the treatment of categorical data describes the important choice of the number of significant digits handled and categorical classification [§A.2] and measures of location and dispersion [§A.3]. This will be followed by a psychometric analysis allowing the proper treatment of ordinal data [§A.4]; separate measures of attributes for each main component of the system subject to assessment; tests of the linearity of the raw data.

Once the raw data is transformed to a quantitative scale, using for instance the Rasch approach, many of the 'traditional' tools of statistics and metrology can then be applied without more ado [§A.5]. This includes expressions of measurement reliability; measurement uncertainty and metrological traceability; precision and trueness; construct alleys; measurement/product separation; significance tests within and between test persons, products, items, etc; radar plots; multivariate principal component analysis; etc.

A.2 Categorical and raw data

An extract from the original raw data from the accessibility questionnaire studies (§2.2) is shown in Figure A.1:

[18] E Svensson 2001, "Guidelines to statistical evaluation of data from rating scales and questionnaires", *J Rehab Med*; **33**: 47–48



id	Q38	Q39	Q40	Q41	Q42	Q43	Q44	Q45	Q46	Q51	Q13
TP2	3	3	3	3	3	2	2	3	3	3	1
TP3	2	3	3	3	2	2	3	2	3	2	1
TP18	3	3		1	3	3	1	1	3	3	1
TP22	2	2	2	2	3	2	2	2	2	3	2
TP25	2	2	2	2	2	6	2	2	2	2	2
TP29	1	1	1	1	1	1	1	2	1	2	1

Figure A.1 Raw data

If one plots [Figure A.1] the raw data, it is evident that, in view of the large dispersion between the ratings of the different test persons (TP) (and also a similarly large dispersion between question responses for each rater), there is little significance in digits after the decimal sign of each raw data value. It is normal practice in metrological data analysis to eliminate all non-significant digits but keeping one digit beyond what is significant in order to avoid rounding errors during data analysis.

In the present study, an additional important observation is that we are dealing with **categorical** data, in which an apparent continuum of observed values of the raw data is transferred to a discrete, classification scale: $v_{i,j,5} = Score(1,...,7)$, with integer category values, and reflecting the ordinal nature of the observed values.

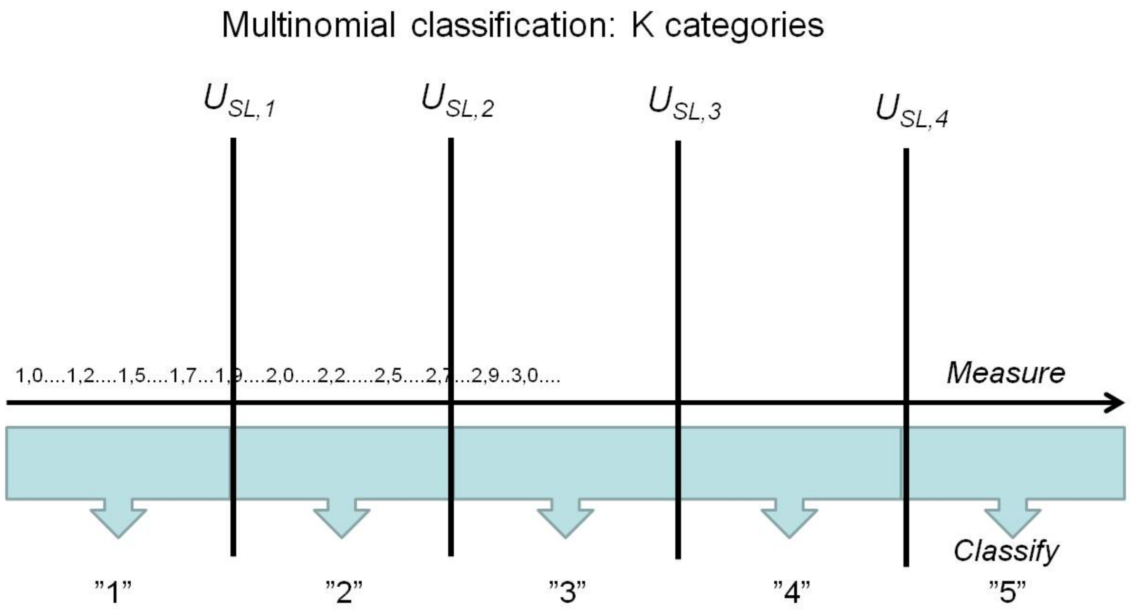


Figure A.2 Multinomial classification

This classification process is illustrated in Figure A.2 for a series of category 'thresholds' (specification limits, $U_{SL,k}$).

A.3 Measures of location and dispersion

In general, a combination of actual dispersion in the involved attribute values as well as apparent dispersion arising from limited measurement quality, will lead to a distribution of the probability, q_k, of classifying data over the categories, k, described by a probability mass function, PMF shown schematically in Figure A.3.

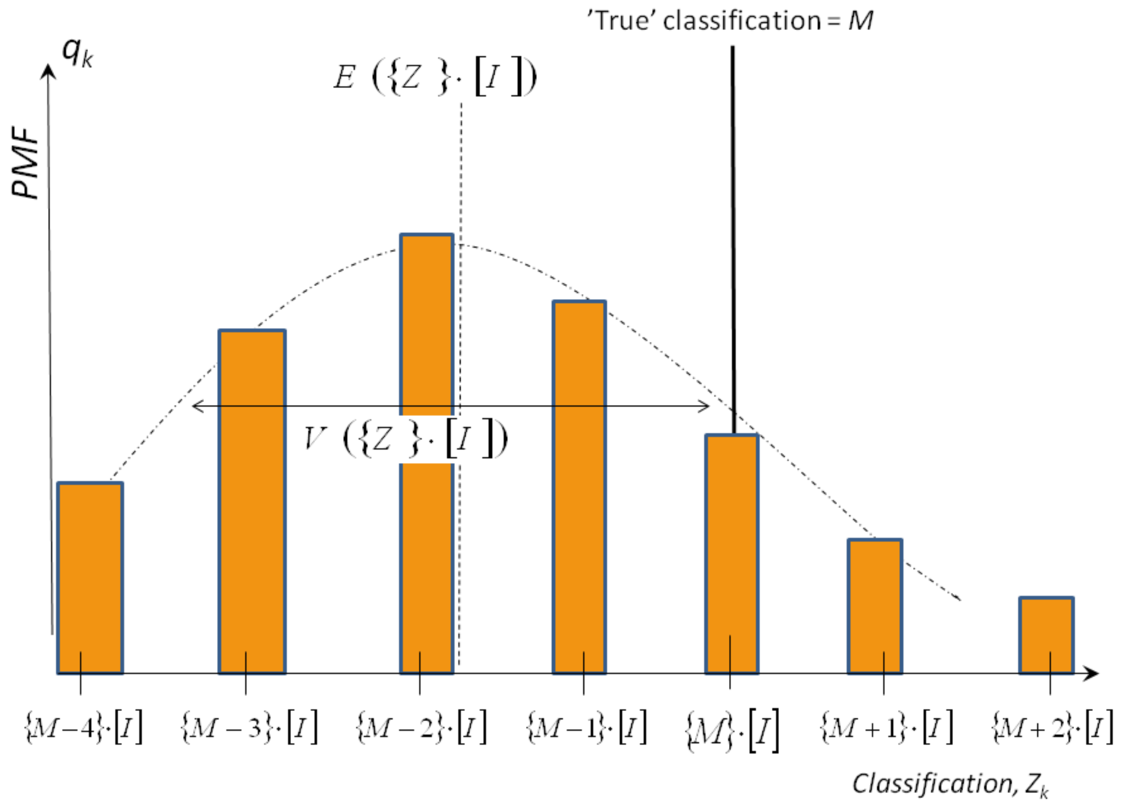


Figure A.3 PMF of classification data

For any one category, *c*:

$$q_c = \sum_{k=1}^{K} p_k \cdot P_{c,k} \qquad \text{(A.1)}$$

combining two factors:

i. the *ab initio* distribution of values where the probability prior to measurement of finding the system of interest in a state of category *k* is p_k

ii. the conditional probability is a ('classification') matrix, $P_{c,k}$, of observing the system in category *c* when the prior state is *k* [Bashkansky *et al*., 2007, 2010][19].

A.3.1 Interval data

Assuming initially measurements on an interval or ratio scale, the expectation and variance of a discrete quantity *X*, obtained from analysis of the probability mass function (PMF) $g_{test} = q_k$, associated with the experimental results (such as shown in Figure A.3), are respectively:

$$E(\{X\}\cdot[I]) = \sum_{k=1}^{C} q_k \cdot (\{m_k\}\cdot[I]) \qquad \text{(A.2)}$$

$$V(\{X\}\cdot[I]) = \frac{\sum_{k=1}^{C}\left[q_k \cdot \{m_k\}\cdot[I] - E(\{X\}\cdot[I])\right]^2}{C-1} \qquad \text{(A.3)}$$

where *C* is the number of discrete levels/categories.

[19] Bashkansky E, Dror S, Ravid R, Grabov P 2007 "Effectiveness of a Product Quality Classifier". *Quality Engineering* **19**(3): 235-244 ; E Bashkansky and T Gadrich 2010 "Some metrological aspects of ordinal measurements", *Accred. Qual. Assur.* **15**:331-6, DOI 10.1007/s00769-009-0620-x

A.3.2 Ordinal data

On qualitative ordinal scales, expressions of classical statistics such as in eq. A.2 and A.3 simply *cannot* be assumed to work. Those expressions derived for quantitative interval scales cannot of course be applied to ordinal scales since distances between different pairs of categories of responses are not known exactly. Sum scores of multi-item assessments; the mean value; standard deviation and calculation of differences for description of change in score do not have an interpretable meaning on ordinal scales [Svensson 2001][20].

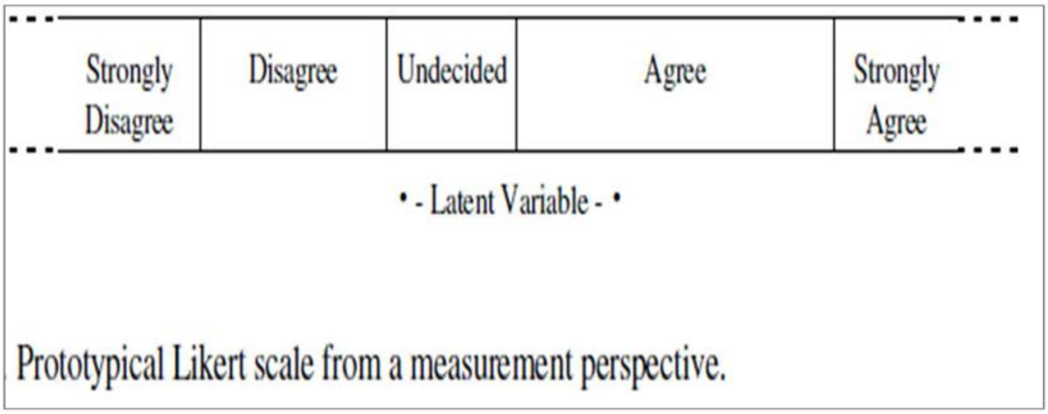


Figure A.4 Example of subjective scoring [Linacre 2002][21]

An example of subjective scoring typical of ordinal scales is where responses on a 5-category Likert scale [Figure A.4] are not linear across the range. Some people ('monomodal') tend to avoid scoring at either extreme of the scale (over-estimating grade '1' and under-estimating grade '5'), while others will tend to avoid scores in mid-range ('bimodal'). Such miss-scoring needs to be evaluated and corrected for, otherwise the reliability of decisions based on data may be compromised. Examples of this are modelled and found in the present study [§5.3].

[20] E Svensson 2001, "Guidelines to statistical evaluation of data from rating scales and questionnaires", *J Rehab Med*; **33**: 47–48

[21] J M Linacre 2002, " Optimizing Rating Scale Category Effectiveness", *Journal of Applied Measurement* , **3:1** pp.85-106

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Farquhar, M. (1995) Elderly people’s definitions of quality of life. *Soc Sci Med.* 41, 10, 1439-1446.

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L R Pendrill, 2011, ”Uncertainty & risks in decision-making in qualitative measurement”, *AMCTM 2011 International Conference on Advanced Mathematical and Computational Tools in Metrology and Testing*, Göteborg (SE), June 20 – 22 2011, http://www.sp.se/AMCTM2011 and World Scientific

L R Pendrill 2014, “Using measurement uncertainty in decision-making & conformity assessment”, *Metrologia* (submitted Feb 2014)

L R Pendrill, B Berglund *et al*. 2010 “Measurement with Persons: A European Network“, *NCSLi Measure*, **Vol. 5,** 42 – 54

L R Pendrill and W P Fisher Jr., 2014, “Quantifying Human Response: Linking metrological and psychometric characterisations of Man as a Measurement Instrument” ”, *Measurement*, (submitted March)

C Sundling, B Berglund, M E Nilsson, R Emardson and L R Pendrill 2013, ”New perspective on the accessibility of railway transport for the vulnerable traveller”, *Joint IMEKO TC1-TC7-TC13 Symposium, Measurement across physical and behavioural sciences*, 4-6 September 2013, Genova, Palazzo Ducale (IT), *Journal of Physics: Conference Series* **459**, 012021, doi: 10.1088/1742-6596/459/1/012021

C. Sundling, R. Emardson, L. R. Pendrill, M. E. Nilsson and B. Berglund 2014, ”Two Models of

Accessibility to Railway Travelling for Vulnerable Elderly Persons", *Measurement*, (submitted March)

Transek. (2005) Äldre personers resvanor och aktiviteter.

APPENDIX VIII

Literature Review on the Constructs of Usability, Disability and Accessibility - Especially in Relation to Railway Travel, C. Sundling.

100915 Catherine Sundling

Literature Review on the Constructs of *Usability*, *Disability* and *Accessibility* - Especially in Relation to Railway Travel

Background

Trafikverket, previously Banverket (National Rail Administration) has the assignment from the Swedish government to adapt the rail way system to persons with disabilities. Since barriers also affect the increasing number of persons with ordinary frailness from old age, it has been decided that they should also be included in this group, as well as children, parents with baby carriages or passengers with heavy luggage. In other words, the environment should be designed for everybody. The goal has been set to present an accessible railway system at 2010 (Banverkets råd och riktlinjer, 2005). The implementation has, however, been slower, so the goal is yet to be reached.

So far, The National Rail Administration has formulated requirements for the railway system. Accessiblity is said to include the possibility to get to and from the station/stop, to be able to move and stay within the station/stop, to board/deboard the train and to be able to move within the vehicle. In order to implement measures leading to better accessibility, clear guidelines for the implementation are needed, though. They have therefore developed policies for the physical railway environment (Banverkets Råd och riktlinjer, 2005). The transport authorities together have also prioritized a net of public transport (railway stations, bus stops, airports etc) that should initially be modified. For the railway system, 60 stations are being made more accessible during 2010-2011 in a project called "Stationer för alla" (Stations for all). A total of 150 stations are planned to be modified until 2015 http://www.trafikverket.se.

Trafikverket uses the principles of "Design for All" in their work, which means aiming at solutions that give everybody a possibility to move in and use the environments without pointing out the disability of a specific individual or group. It means that actions taken should not be concentrated on one group only, but aiming at increasing the quality for all users and lower the need for specific solutions. Another principle in their work is the "whole journey perspective" where the journey is seen as a chain of different details including everything from the planning stage to reaching the destination. Trafikverket also participates in an international co-operation in developing ISO-standards for accessibility and usability in the built environment, SIS TK 453. The different modes of railway transport included in the responsibility of Trafikverket are cargo transport as well as long-distance, regional and local passenger transports, tramway and underground (Banverkets forsknings och innovationsstrategi, 2007, Banverkets råd och riktlinjer, 2005).

Regarding the present study, Banverket stated in the project plan that various measures can be implemented to improve accessibility, but it is not obvious which actions have the greatest positive impact and are most cost-effective. The purpose of the project is therefore to develop a methodology to measure the extent to which the disabled passengers can use the rail transport system as a part of the whole trip. The measurements will be used to evaluate accessibility and to target improvements in areas where they have the greatest impact. The main goal is to make the rail way system more accessible for persons with disabilities.

In order to improve accessibility and usability, a first prerequisite is to define the central concepts, especially in relation to railway travel and to review how accessibility and usability has been measured previously.

Definition of usability

The ISO (International Organisation for Standardization) 9241-11 definition is:
"the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." (Bevan, 2001)

Measuring usability

Much of the usability research is made in the HCI (Human- Computer Interaction) field where software or computing hardware usability is measured in different ways. **Hornbaek** (2006) reviewed 180 studies in order to find current practice in measuring usability and found that there are some common problems with the measures, for example whether they are actually measuring usability and if they cover the whole construct of usability. In order to cope with these problems, he recommends being careful in choosing a measure that is relevant in the particular context. For instance, depending on what level of complexity a task is considered, the measurement has to be appropriate. At a 'micro level', tasks are typically of a short duration in time and have a low level of cognitive or social complexity while at a 'macro level', they are more complex, need more time to be executed and thus show larger individual differences. Therefore, measurements must be chosen according to these factors.

When dealing with micro issues, typical measurements can include the number of completed tasks or task completion times, while usability at a macro level can measure aspects of quality, learning or sociability. Hornbaek concludes that studies with a macro perspective are rare, often simple measures at a micro level are used, when trying to cope with the complexity of evaluating usability. According to Hornbaek, it seams dubious that decomposing macro tasks into micro tasks and reasoning about usability based on micro tasks only, should be a possible way to measure usability.

Hornbaek also concludes that some important aspects of usability are rarely addressed in the studies investigated, for instance long-term use and development over time. What if users compensate over time for initial usability problems? If the study duration is brief, this can not be discovered.

He recommends six types of measures, three "objective" - measures that are not dependent on users' perception and three "subjective" or self report measures – measures that concern users' perception or attitudes. The objective measures are expert assessment, comprehension, time, usage patterns, learnability, physiological usability and reflex responses. Subjective measures are: users' perception of outcome, subjectively experienced duration, mental workload, perception of task difficulty and validated questionnaires

The aspects of usability to be measured can, according to Hornbaek, be divided into

- **effectiveness** (outcomes)
- **efficiency** (interaction process)
- **satisfaction (**users' attitudes and experiences)

	Usability aspects	Objective measures	Subjective measures	
	Outcomes (effectiveness)	Expert assessment, Comprehension	Users' perception of outcome	Long term use and developments over time?
Relations between aspects?	Interaction Process (efficiency)	Time, usage patterns, Learnability	Subjectively experienced duration, mental workload, perception of task difficulty	
	Users' attitudes and experiences (satisfaction) on tasks?	Physiological usability, reflex responses	Validated questionnaires	Macro or micro perspectives?

Relations between measures?
Valid and standardized measures?

Lewis (1993) describes research at IBM in the field of usability measurements with questionnaires. He divides usability measures into subjective and objective measures as well. He concludes that in most usability evaluations, both subjective and objective quantitative data is gathered in both a context of realistic scenarios-of-use and descriptions of the problems that representative participants have in trying to complete the scenarios. Subjective usability measures are often responses to Likert-type questionnaire items that assess user attitudes. Subjective measures are more important than objective measures when user satisfaction is the development goal. Most of the questionnaires Lewis describes are having questions with 7-point graphic scales with choices from "Strongly agree" to "Strongly disagree" with consistently positive statements, while one has statements like "Ease of Performing Tasks" and a 5-point scale with choices from "acceptable as it is – very easy" to "needs a lot of improvement" and an "unable to evaluate" choice.

Disability and Functional Limitation

The term 'disability' (funktionsnedsättning) was in 2007 defined by Socialstyrelsen as a reduction in physical, psychological or intellectual ability. A 'functional limitation' (funktionshinder) is defined in relation to the environment, that people are excluded in some way. It can deal with everything from inaccessible information, stairs and doorsteps to attitudes. The use of the term 'handicap' as a synonym is advised against since it can be perceived as stigmatizing.

Accessibility versus Usability

In the study of disability in relation to different environments, the construct of “accessibility” appears to be more frequently used than “usability”. Fänge and Iwarsson, (2003) and Iwarsson and Ståhl (2002) are discussing the two constructs and challenge current terminological usage. They argue that the concept of ‘usability’ implies that any person should be able to use the environment on *equal terms* with other citizens. Accessibility is a necessary precondition for usability and information on the person-environment encounter is imperative. However, the personal and environmental components are more based on individual interpretation and expression, when included in usability, than when included in accessibility. It means that psychosocial factors influence a person’s definition, for instance self-image, motivation, social pressure and expectations. Most important, there is a third component distinguishing usability from accessibility, namely the activity component: Usability is explicitly transactional in nature, implying that the personal, environmental, and activity components are more interwoven than the personal and environmental components of accessibility.

Measuring accessibility in the transport sector

Defining accessibility: The concept of accessibility is wide and might not be easy to catch. Gould (1969) described it as ‘a slippery notion…One of those common terms that everyone uses until faced with the problem of defining and measuring it’. Different definitions are used, depending on the goal of the research and goals vary greatly since accessibility research is conducted throughout different fields; geography, economics, occupational therapy and psychology to name a few. According to Litman (2003), for instance**,** accessibility can be defined as the ability to reach desired goods, services, activities and destinations – together called opportunities. TSG (Transport Studies Group, 2005) describes the primary components in accessibility as the individuals, their desired activities at given destinations and the link between the two. Even though there has been an increased use of the concept of accessibility in transport planning in recent years, the definition has not become more uniform or generally accepted. The general key distinctions though, in modern definitions, are that accessibility is seen as an attribute of people and of places (Envall, 2007).

Accessibility context: TSG (2005) states that, in the United Kingdom, the concept of accessibility is used in two different contexts; either to describe design characteristics that can enable or inhibit their use by people with impairments or to describe the ease of reaching opportunities or the ease of being reached. Envall (2007) means that ‘accessibility’ is applied either in planning, in measuring how a transport network performs or in relation to disabled users’ ability to use the travel chain.

Accessibility measures**:** Not only are there many different definitions of accessibility, there are also many different ways of measuring accessibility, depending on what is being measured, as different accessibility measures capture different dimensions of accessibility (Makrí and Folkesson, 1999). Also, there is no consistent terminology for describing different accessibility measures. Two different starting points in measuring accessibility are **place** accessibility and **individual** accessibility**,** in other words if measures are describing people or places (TSG, 2005). The most fundamental accessibility measures relate to place accessibility; *distance measures*, counting the distance from one location to another or from one location to different opportunities. Another distance measure is average distance; from all departure points in the area to one destination, or from one departure point to all destinations. Individual accessibility measures, on the other hand, take a particular person's needs and abilities into account; mobility, attitudes, travel patterns, monetary and time resources (Makrí, and Folkesson, 1999, Envall, 2007, Church, Frost and Sullivan, 2000).

In a try to categorize measures, Envall (2007) finds a distinction between studies that treat all destinations within a specified interval equally - **cumulative opportunity** - and measures that gradually reduce the value of destinations further away, **gravity-based**. Other studies are based on **utility theory** in which variations of destination attractiveness are included (more about attractiveness variables below). Utility-based measures assume that the individual tries to maximize her or his utility.

The observed or expected **cost** of travel can be defined to include time, economic cost and effort or convenience, involved in travelling. This can sometimes be a more appropriate measure than distance, especially in urban areas (Morris, Dumble and Wigan 1979)

Morris, Dumble and Wigan stated in 1979 that accessibility measures relate either to the **potential or opportunity** to travel, which could be called **'supply'** factors, or to actual **travel behaviours - proof of access.** Examples of potential or opportunity measures are number of opportunities that can be reached by a car within a given time period compared to those that can be reached with public transport, or equality of opportunity, for example, what is the proportion of citizens having a bus stop within a given distance (Morris, Dumble, Wigan 1979, Envall, 2007).
An example of actual travel behavior is the travel patterns for a specific group. This might be important knowledge in order to assess travel constraints and also to classify the population meaningfully in relation to transport accessibility - who is using public transport? For example what percentage of the passengers has a disability? What kind of functional limitations do they have, or how many are children or seniors? Passenger profile surveys might be combined with an estimation of total trip making by the different sub-groups of passengers. This kind of survey is made through estimates or observations by staff or by interviewing passengers (Rickert, 2005). A limitation is that observed behaviour does not necessarily correspond to accessibility since people inhibited from travelling are excluded from such studies. On the other hand, it can indirectly show gaps between accessibility and needs, for example if people are using detours because other alternatives are perceived as sub-standard (Envall, 2007, TSG, 2005).

Supply factors and actual behaviours are of fundamental importance, but not sufficient. The probable interest of a destination reached is also important – in other words the motivation of the traveller or the **demand** to reach a specific goal (Morris, Dumble and Wigan, 1979). Knowledge about motivation for a certain journey can give a deeper understanding of travel behaviours, for example. **Attractiveness** variables reflect the amount of activity at a certain destination. Both supply and demand are then taken into account. Accessibility to employment depends not only on job opportunities in a given area, but also on the number of persons competing for them. **(**Morris, Dumble, Wigan 1979, Makrí and Folkesson, 1999, Envall, 2007). All these measures can be calibrated for different types of opportunities or different segments of the population (Makrí and Folkesson, 1999). If there is supply but no demand, accessibility becomes meaningless. If, for example, the travel links are good between one residential suburb and a another part of a city with a highly specialized labour market, people in the residential suburb can not use the advantage of good accessibility, if they do not have the skills needed (not for employment reasons, at least) and demand is thus low. Conversely, people living in a suburb with bad travel links to appropriate employment opportunities, can not benefit from the good supply at the destination in spite of high demand. So for accessibility to be relevant, both supply and demand of both transport and goals at the destination are important (Church, Frost and Sullivan 2000).

Pre-trip information about accessibility of a destination might be crucial. If you are planning a holiday trip, but are unable to get information of whether there are accessible hotels or not, you might not be able to go at all, even if it actually would have been accessible. If an accommodation operator does not understand what accessible or barrier-free accommodation entails and thus is unable to provide accurate and detailed information, it represents a barrier in itself. Sometimes, the accommodation is described as accessible, but is found not to be by the traveller, in the worst case as late as upon arrival (United Nations, 2003).

Not only is accessibility of the destination and transport system important. If it is difficult to reach your local station or bus stop from your home, public transport might not be perceived as accessible. **The local residential environment** is thus important when measuring accessibility, as well as on demand service and other ways of reaching the station or bus stop. Ståhl and Iwarsson (2007) found that when barriers in the local residential environment were reduced, the proportion of participants rating public transport as the main barrier for engaging in activities away from home, declined.

TSG (2005) describes four different ways of categorizing **accessibility needs (**or demand);

- *Expressed* accessibility needs: revealed by observations of travel behaviour.
- *Community* accessibility needs: potential accessibility based on assessment of society's expectations of basic needs.
- *Stated* accessibility needs: people's views, often revealing needs which have not been identified or measured using the other techniques.
- *Comparative* accessibilities: distribution of access opportunities or accessibility gaps by people, group or location.

Motivation is an important concept in accessibility, in relation to the destination, mentioned earlier, but also because travellers' past experiences form expectations of future journeys (Prebensen, 2006). Also, an environment is not always either accessible or not for a certain person - there is a 'grey scale' in between, where, even though something might be seen as accessible from the outside, the effort needed of travelling might be perceived so demanding that the motivation to choose the alternative is low as long as others exist. (Iwarsson, Jensen and Ståhl, 2000). Then, accessibility may be most meaningfully measured by the *effort* involved (Morris, Dumble and Wigan (1979). Knowledge of other alternatives might thus be of importance to understand motivation and he decision making process. Also, there might be persons with no *travel experience*, who have never travelled with public transport because of their disabilities and have to overcome fears of a novel experience to be motivated (Rickert, 2005).

Motivation and the individual experience of a journey can differ even if the effort and travel experience are the same. **Self-efficacy** refers to people's belief in their own capacity in a given situation; a person's judgement of his or her own capability. People cultivate their self-efficacy in different areas of life and it is possible to have, for instance a high organizational efficacy but at the same time a low parenting efficacy. Thus, it is a belief system with differentiated self beliefs linked to distinct areas of functioning. Self-efficacy effects behaviour, outcome expectations and how much effort a person is willing to make in order to reach a specific goal (Bandura, 2005). Self-efficacy in relation to travel can thus be of importance as a motivational factor for the individual.

Jensen, Iwarsson and Ståhl (2002) found that even if many persons perceive barriers in travelling because of specific details in **the travel chain**, others presumably manage single environmental demands, but with the total demand of the many links of the travel chain, taken together it is too demanding. For persons with cognitive disabilities, the complexity of changing from a bus to a train, for instance, can be very difficult since the user is forced to be alert during the whole journey (Rosenkvist, 2008). In other words, the sum of the details can be different than each detail measured separately. Therefore, it is important to measure the whole journey – also compare with Hornbaek's (2006) discussion mentioned above, of studies trying to measure usability on a macro level with micro measurements. In this context, the whole journey perspective would represent a macro perspective; the social and cognitive complexity is larger, duration in time is longer and individual differences are larger, with vast variations in outcome as a result, and the measurements have to be appropriate for a "whole journey perspective".

Accessibility measures can also be divided into either **direct measures or proxy measures.** Direct measures are, for instance, the number of disabled persons using a specific bus link during a certain time frame and one-way trips may be evaluated as a measure of service efficiency. P**roxy** or **surrogate measures** are substitutes for the direct measure, for instance the increase in number of visitors to a special rehabilitation centre after introducing a low floor bus going by the centre. Both measures can be repeated to measure changes after an intervention and long term to see if the change is persistent (Rickert, 2005).

TSG (2005) have come up with a "checklist" of factors that they find important in measuring accessibility;
- travel time
- cost of travel
- location of facilities and services
- method and timing of service delivery
- some environmental, health and safety factors
- transport reliability
- fear of crime
- knowledge of available travel and service choices
- travel horizons

<u>Accessibility barriers</u> could be divided into:

- **Physical barriers** which can relate to access to trains, stations and station facilities as well as the location of the activity itself. Also, it can regard assistance needed in order to make the journey. Not only disabled people can experience physical restrictions, even others, for example people carrying heavy shopping or being accompanied by young children. Normally, there is a wide spread within the population of acceptable limits, which makes setting thresholds difficult in accessibility planning. For persons with cognitive disabilities, a complex and constantly moving physical environment can be difficult to manage. Cars and pedestrians moving, traffic lights changing etc, means many simultaneous impressions which can be difficult to sort out (Rosenkvist, 2008).
- **Financial barriers** include affordability, competitiveness of fare structure.
- **Information barrier**: available and comprehensive information.

- **Confidence barrier**: whether the whole journey can be made with certainty, if there is trained staff to help.
- **Time (or temporal) barrier**: if booking arrangements can be made in time, if the train can be reached in time or when there is a mis-match between the times at which services are available and people are able or willing to access them, or when the required travel times exceed some maximum threshold. Walking time to stations and within stations is important and this is also a matter of topography and distance.
- **Spatial,** relating to distance. It can regard walking distances which are, as above, dependant on topography and other factors. Also, as faster travel options have become available, people have travelled further also implying that trip complexity is growing, journeys are increasingly being composed of trip chains (TSG 2005, COST, 1999).

Another way of mapping accessibility barriers, focusing on individual accessibility measures, is by dividing them into:
Capability constraints: for example physiological or personality constraints. It can also refer to skills, like car driving capability or availability issues like owning a car.
Coupling constraints which refers to co-existing with other people, for example have a meeting at a certain time and place.
Authority constraints reflect general rules or laws that can limit a person's access (Yo and Shaw, 2007, Hägerstrand, 1991).

All of these constraints appear in a space or time frame and are thus examples of **space-time measures**. Coupling constraints refer to groups of people while capability- and authority constraints refer to individuals (Yo and Shaw, 2007). A potential barrier related to the 'confidence barrier' or the 'capability constraints' is the perception of one's own ability to travel which can be related to **self perception** - the way people learn about and define themselves compared to others - as well as to travel experience and self-efficacy, described above. Previous travel experience has been shown to affect tourist perception and motivation (Prebensen, 2006).

There can be a problem if standards and regulations are written to ensure "**absolute access**" only, for example that there should be at least one accessible route provided, but "**relative access**" is ignored. Relative access refers to the fact that there are differences in access for different individuals, groups, sums of activities or frequencies of an activity[1]. Imagine a situation in which a person can take the steps and go straight to the destination while another person has to go to the other end of the corridor, wait for the elevator, take the elevator down, use a ramp at the other side of the house and go around the house in order to reach the same destination. This can be measured in distance, time and effort needed and it can be expressed in figures - for instance that it takes a person in a wheelchair 2,25 times that of an ambulatory person to reach the same destination. In absolute terms the destination is accessible but if relative access is taken into consideration, the effort involved, which might also be linked to motivation, might be too large. Relative access measures can be used to sum up activities and frequences, to compare accessibility for different individuals or groups. Using the measure in understanding the impact of different design alternatives can help finding the most cost effective improvement in access (Church, 2003).

In comparing different possibilities, **thresholds** for different groups can be found. For example, what are the acceptable walking distances to the railway station for older people or those with mobility impairments? Not only distance but also topology is important to take into con-

[1] The concept of "Relative accessibility" is often used with another definition; the physical separation between two locations (Envall, 2007)

sideration. Different modes of travel or different goals of the journey might be compared as well, in relation to effort and motivation but also in relation to time and outcome, for instance (TSG 2005). Accessibility standards are often set by using indicators of a fixed distance, cost, time distribution or a score. For instance, a special service of some kind should not be located further away than x meters from a particular group of households. This way, accessibility indicators can be designed to target certain needs of certain groups (Envall, 2007).

Satisfaction, a central concept in usability research, can also be useful in measuring accessibility within the public transport sector. The 'transaction-specific' approach in consumer satisfaction focuses on single transactions or encounters (Friman, 2000), while the 'cumulative satisfaction' approach regards the consumer's overall experience of consuming a product or service. A traveller's satisfaction with a trip might be the result of the evaluations of single elements of a journey as well as the customer's expectations before and during a trip. Consumers often choose activities based on their expectations and after consuming the product, the actual performance of the activities is compared to the expectations. If the performance is better than the expectation, it leads to a positive disconfirmation and vice versa. According to Oliver and Swan (1989) consumer satisfaction is related to the costs spent (the input) and the anticipated reward (the output). For travellers, it would imply that if they receive benefits based on the time, effort and economic cost they have invested, the journey has been worthwhile (Prebensen, 2006). The measurement of satisfaction has been approached for instance with focus groups, household surveys, mailed questionnaires and telephone surveys (Rickert, 2005).

Satisfaction has often been measured with attitudes towards a product or service (Friman, 2000). A potential problem in measuring satisfaction, using questions about attitudes, can be shown in the belief-sampling model. In the model it is assumed that people have ideas stored in the long-term memory that can be retrieved in response to an attitude question. The attitude retrieved at a specific time, is however a function of different qualities of the ideas retrieved at that specific time and situation. Since the memory retrieval system is variable, attitudes can thus also vary between situations and points in time while satisfaction is seen as a direct response to encounters with a product or service and is assumed to be a source for attitude change (Hastie, 2001, Friman, 2000).

In **the theory of planned behaviour**, it is assumed that the more favourable the attitude, subjective norm and perceived behavioural control, the stronger is a person's intention to perform a particular behavior. Also taking past behavior into consideration when predicting a certain behaviour has been found to increase accuracy (Gärling, Gillholm and Gärling, 1998, Bamberg, Ajzen, Schmidt, 2003).

Studies addressing accessibility in the transport sector

Friman (2000) studied consumer satisfaction with public transport services using the critical incidents technique. She studied characteristics of critical incidents as well as perceptual, cognitive experiences and affective responses of negative critical incidents. She found that frequency of negative critical incidents, defined as disconfirmation of expectations, affected overall satisfaction with public transport negatively and that satisfaction was related to affective reactions of the incidents. Important parts for consumer satisfaction in public transport were found to be treatment by employee, reliability of service, simplicity of information and design.

TSG (2005) in Great Britain carried out a research project with the aim to develop and apply more refined measures of accessibility, sensitive to perceptions and needs of different social groups. They used two already existing tools for measuring travel time in London; CAPITAL and PTAM and enhanced them in terms of measuring accessibility and displaying it. They also developed a new tool, WALK (Weighted Access for Local Catchments) and combined the three tools for the study. The purpose was to show how standard walks catchment areas change shape and shrink once the impedance effects of different types of barriers on various population groups are taken into account.

The researchers created a detailed pedestrian network for each local study area and linked different types of barriers to the network. Values specific to each population group were added and next, maps were created to show how catchment sizes varied for different social groups for daytime and evening conditions. They could then, for instance, measure accessibility of a specific bus stop when different walk speeds were applied. One of the groups investigated was older people and the researchers could measure the accessibility for them, given their walk speed to a specific bus stop, which for example lacked seating and shelter, also including the area near the bus stop in terms of road business, lightning etc.

The three tools were used in combination to show how accessibility varied during different times of day, set of public transport modes used, reflecting different travel costs and interchange requirements. They were then presented to focus groups comprising representatives of selected social groups, using examples of outputs being relevant to their particular activity and travel needs. The groups were asked about their comprehension of the maps and they were also asked to compare the tool outputs with their own perceptions of accessibility. The maps were found to be comprehensible, relevant and useful.

Envall (2007) studied accessibility planning in his doctoral thesis and one of the studies was conducted as a survey directed to transport planners. The goal was to investigate difficulties in implementing Accessibility Planning and also planners' attitudes to it. A questionnaire survey was developed, first as a pilot questionnaire, tested on a handful of people with knowledge of the Accessibility Planning process. The results suggested the use of mainly multiple choice questions to improve the response rate and make the answers easier to interpret. The sampling was made from a list of local authorities and the questionnaire was sent by post.

The first part of the final questionnaire explored Accessibility Planning tasks that the authorities had progressed to date, beginning with relatively easy to fill in multiple-choice questions in order to make the respondents more willing to take on the task. The second part explored, among other things, the usefulness of Accessibility Planning to the authorities. The scales used to test the research propositions ranged from "not at all useful" to "very useful" and "strongly disagree" to "strongly agree". Since the multiple-choice questions reduced the information gathered and this could have made it difficult to understand underlying issues, open-ended follow-up questions were added. The third part examined difficulties experienced by the planners and potential conflicts between Accessibility Planning and other policies.

Another part of his thesis referred to pedestrians' needs, with questions concerning different ways of reflecting pedestrian behaviour, improving accuracy of accessibility indicators or what environmental attributes are most important for accessibility of main pedestrian groups. This study was made as a questionnaire study as well. The design was decided by arranging a workshop with 10 research students, discussing their own pedestrian route choices. Also, findings from an earlier study within the thesis helped in deciding in the design of a preliminary questionnaire. Colleagues gave feedback on different versions of the survey as well. The questionnaire was then distributed by mail and personal handout. Also, interviews were conducted.

The final questionnaire was shortened compared to the preliminary version and divided into two sections with multiple choice and open-ended questions, asking how often respondents walked in their local area, reasons for avoiding walking to particular destinations and what local improvements, if any, would make them walk more. It was analysed in different ways, for example by comparing the respondent's normal route with the shortest distance route available to see to what extent the pedestrians took the shortest distance route available. Also, characteristics like gender and age of those taking detours were investigated. Another part of the analysis was to create "restricted networks" which omitted links that had special characteristics, like unlit streets. The shortest paths in the restricted networks were then compared with the respondents' normal routes investigating the possible role environmental attributes played as barriers for walking. It was assumed that, if adding environmental attributes could explain detours, these attributes could be added into a new accessibility algorithm, thus improving the capability to measure accessibility.

Stradling, Anable and Carreno (2006), measured satisfaction with travel modes. As mentioned earlier, it is common to apply the approach that if the experience of a service exceeds the expectations of the client, then satisfaction will be high and vice versa. The researchers examined the differences between the desired level of a service and what was actually delivered and weighted the gaps to find out their relative importance and to see where improvements were most required. This was made in six steps.

The first step included literature review, focus groups, discussions and interviews to find elements of the journey experience, including both instrumental and affective aspects. In step 2, users rated performance and importance using 5-point agreement/disagreement scales. In step 3, a disgruntlement measure was derived by cross-tabulating performance against importance ratings for each element. In step 4-6 prioritizing potential areas for remediation was made. Disgruntlement and importance were then plotted and zoned in different priority zones, with zone 1 as top priority (high disgruntlement and high importance). For bus users, it was for example time constraints. The method put focus on passengers who found it important that there was a gap between actual and ideal service on a particular service element. By combining performance and importance, it was possible to identify the largest service quality gaps.

A study within the **PT access (**2009), a European project co-funded by the European commission, concludes that accessibility measures in public transport in Europe, are often implemented without evaluation. When it is done, different forms of evaluation procedures are chosen and Cost and Benefit Analysis (CBA) still dominates. It seems, though, that it omits important measures, for instance quality of life, and must therefore be broadened. Also, participation processes, which certainly play an important role in evaluating accessibility in public transport are not sufficient for a holistic assessment.

The assessment tool advocated in the PT access study is focused on opportunities, behaviour and satisfaction. The study is made in the form of interviews with key representatives as in the study above. They assess the influence of the (planned) measure on system performance, quality of life, and on individual behaviour. Indicators are developed to support the evaluation process. Monetary and non-monetary effects like lower fuel consumption or social exclusion/inclusion are included. An evaluation tableau is developed to summarise the important information.

Mediate (Methodology for Describing the Accessibility of Transport in Europe, 2010 (?)) is another project (co-)funded by the European Commission. The objective of the project is to establish a common methodology for measuring accessibility in European transport. The project is ongoing and the first step is to develop accessibility indicators highlighting different aspects of accessibility pointing out strengths and weaknesses. This will be followed by a self-assessment tool, a good practice guide and a final report.

The indicators are identified, based on literature review, input from local authorities and operators, users and accessibility experts. Development and implementation is seen as a dynamic process of sequential steps bringing accessibility up to a higher level. The indicators are divided into

- policy indicators, which regard policy and investment on the one hand and service operations and standards on the other
- performance indicators; information and ticketing systems, vehicles and built environment and seamless travel

In the project, it is pointed out that the whole travel chain as well as different requirements of various groups of passengers must be taken into consideration in measuring accessibility. Accessibility is a relative concept and depends on the individual, the environment, the activity and the purpose of the task. Important parts of accessibility have been found to include information, a barrier-free built environment, universal design, high operational standards, intermediate solutions between mainstream and individual options, appropriate vehicle design and comfort and safety. It is important to measure usability of the system as experienced by the user and to find out what is critical and how actions will improve the overall experience. Also, cooperation between operational service providers, infrastructure managers and local authorities is important so measures match and support each other. Another significant part is the transport delivery chain; staff training and maintenance procedures for example as well as addressing the gap between planned and actual delivered service and measuring the quality standards.

There is a number of studies focusing on developing new IT-based information systems. **Matthews, Beale, Picton and Briggs** developed an individual accessibility guide for wheelchair users in urban systems. They initially measured needs, perceptions and experiences through a questionnaire, focus group and survey techniques. Next, they implemented the barriers found, into a GIS (geographic information system). In doing this, each feature was assigned a relative value expressing a level of impedance. These values were derived from either field trialling or the consensual perception of wheelchair users. Since the same barrier (for example a specific surface type) can be found in different locations along a route, it was stored independently so any change could be readily incorporated. Also, many barriers are directionally dependent (for instance a slope) and this was also taken into consideration. Accessible routes are, in the system, determined in evaluating all possible routes from the starting point to the next destination. The route with the lowest impedance will be selected as the optimal route given the characteristics of the specific individual.

The tool can also be used in highlighting problematic parts of the urban landscape and show how changes in urban design can impact accessibility as well as providing an inventory of the barriers perceived by the wheelchair users where the cumulative effects, for example measured in time, are made visible.

Becker, Franzen, Heck and Dirks (2006) developed an information system to improve accessibility for people with reduced mobility. To analyse user needs, they classified target groups and then investigated users' requirements and priorities with rehabilitation experts and representatives of various groups of disabled persons in public transportation. They rated the importance of attributes of vehicles, buildings and information systems etc. prior and during travelling and evaluated the relevance of the attributes for the user focus groups. They found, among other things that the PC was the primary medium for planning the journey, while spoken information (telephone) is important before and during the trip. Also, mobile phones are applicable for speech or text information, depending on the user group.

<u>Studies addressing accessibility for disabled persons in the transport sector in Sweden:</u>

According to Statistiska Centralbyrån, **SCB** (Davidsson, 2001), a fifth of the Swedish population or 1,3 millions are disabled, meaning vision- or hearing deficit, mobility disorder, severe asthma or allergy. In 1999-2000, SCB studied accessibility in the transport sector for persons with disabilities. Since there are no sampling frames with information of disability, SCB ordered additional questions in the routine studies about living conditions conducted regularly in Sweden, mainly through interviews, called ULF. The most common mode of travel in Sweden is by car, both for persons with and without disabilities. Around 150 000 persons in Sweden are excluded from public transport because of disabilities. 60 000 are travelling at least a few times a month, but with difficulty. Most persons with disabilities, though, have no difficulties travelling with public transport according to SCB.

Concerning train journeys, it was found that 15% of the disabled persons are travelling by train at least a few times a month, and it is most common in the big cities. A main reason for not travelling by train was that it had not been of interest - there was no place to go that could be reached by train. A smaller part of the participants answered that they preferred to go by car, but 15 % reported that their disability or disabilities excluded them from travelling. This did not regard those with hearing deficits or severe asthma/allergy, though. Another reason was living far away from a station, that it was too expensive, the connections were not good enough or that it took too long to travel in that mode. The majority thought they would continue to travel about as much in the future as today. The main problems in travelling with public transport was getting on and off the vehicle but also included need for personal help, for example. These problems regarded mainly long-distance trains.

Jensen, Iwarsson och Ståhl (2002) studied accessibility problems for persons with disabilities using the travel chain perspective in public bus transport. They chose two different measures. First, by developing a measuring instrument – "The Travel Chain Enabler" (Iwarsson, Jensen and Ståhl, 2000) independent environmental assessments could be performed. The second measure was "The Critical Incident Technique" where the researchers observed participants during the travel chain. The two instruments were combined and two types of incidents were studied; accessibility problems that called for intervention and accessibility problems that the person overcame. Sub-sections of bus journeys were entrances, estate environments, public outdoor environment, bus stops and low-floor buses.

The researchers found a number of incidents registered by the observer, the participant or both. They concluded that in order for persons with functional limitations to use conventional transport systems it must be possible to make valid predictions of accessibility. Because of the dynamic nature of travelling, conditions might change from one time to another; the elevator might be out of order or the bus driver might stop at various places along the platform. Therefore, in order to understand more about the person environment encounter, it is important to assess accessibility problems in detail.

"The Travel Chain Enabler" was based on "the Housing Enabler" a measuring instrument Iwarsson had developed for assessment of the housing and immediate outdoor environment (Iwarsson, Jensen and Ståhl, 2000). "The Housing Enabler" was later reduced into a shortened form for screening purposes (Carlsson et al, 2008). The methodology for doing this included initial identification of environmental barrier items conducted with quantitative and qualitative methodology.

- Quantitative method: based on statistical analysis and the use of existing databases. Experts involved represented community health sciences, occupational therapy, gerontology, psychology, traffic planning and engineering, data management and statistics. The researchers developed a new approach to statistical analysis since there was no standard statistical method applicable for the study. An "Index of variance contribution" was developed to make it possible to rank environmental barrier items according to their respective contribution to the variance of the Housing Enabler accessibility score. Three empirical databases were used, representing people with a wide range of different functional capacities, living in different types of housing in three countries with different housing standards and building traditions.
- Qualitative methodology: based on an expert panel procedure. To ensure validity of the study, the core items had to comprise environmental barriers generating accessibility problems for many types of functional limitations and they also rated the severity of functional limitations to prioritize higher degree of severity before lower. They also included barrier items critical for safety and barriers not applicable to all kinds of housing.

Both groups – the statistical analyses and the expert panel - arranged, without exchange of information between them, a list of core items each. The lists were then merged and through discussions between representatives from the groups a final set of 61 core items was decided.

The MAPLE project (Grönvall, Ståhl and Iwarsson, 2005) co-founded by the European Commission, focused on persons with learning difficulties and persons with mental health problems in Sweden by interviewing representatives from the transport sector and interest organizations to find out the level of accessibility of public transport for the groups in question. Their findings were that work has been done to improve accessibility, for instance changes in the "Planning and building act" from 2001and "The Whole Trip" project which has been a common project the National Road Administration, the National Rail Administration and the National Public Transport Agency. Practical results include low-floor vehicles, stop announcement/display and stops/infrastructure among other things.

They stated that no organization had, so far produced specific measures for persons with cognitive functional impairments - the main emphasis was on limited mobility and impaired vision as reflected in policy documents. Some of the measures taken could make things easier even for this population though. Pictographs and special announcements are examples of that as well as some of the measures taken to simplify orientation - building bridges over tracks instead of tunnels for instance. Several transit authorities were in the planning stage of changing ticketing systems in order to accommodate as many functional impairments as possible and the special Transportation Service is used by many persons with cognitive impairments.

Suggestions for the future include pictographs, real time information, loudspeaker information, personal technical aids and special service personnel. They also stress that individual travel training for passengers and education and training of staff are important factors no matter how many other measures are taken.

Transportstyrelsen (transportstyrelsen website) measured accessibility with interviews for persons with disabilities, between 2002 and 2005. A postal study was conducted with persons having hearing-, mobility- and cognitive disabilities as well as asthma/allergy and persons having become deaf in adult age. Persons with vision impairments and a control group were interviewed by telephone. The total population was 2015.

Questions asked included travel habits, latest journey (for those who had been travelling the last 24 months) and reasons for not travelling (for those who had not travelled during the last 24 months). The study included statements like “It was easy to…” and 15 alternatives to rate, for example “to order attendance” or “to have access to information at the station”. Several disability organisations were involved in the project. Regarding train travel, it was found that persons with cognitive disabilities had the largest difficulties travelling by train, followed by mobility- and visually disabled.

Fewer than six out of ten in the disability population reported that they experienced travelling as easy. Those who reported the greatest difficulties were persons with more than one disability, persons with visual impairments and persons with cognitive disabilities. Persons with more than one disability mentioned difficulties with getting to, on and from the train, allergy questions and information as the main problems. Persons with visual impairments mentioned moving within the station as well as information, as the largest difficulties and persons with cognitive disabilities reported information during planning and getting to, on and from the train as the greatest problems.

PT Access, mentioned above (2008), studied the current state of accessibility of transport systems around the European Union. In each country, a study was conducted in the form of interviews with a representative of persons with disabilities, a transport operator and a governmental authority. Thus, the goal was to give an overview of the state of accessibility of public transport in each country based on the viewpoints of certain key persons. The interview contained the following topics: statistical data, legal and regulatory framework conditions, organisational framework conditions, accessibility of passenger information, ticketing, stops and stations, vehicles, safety, reliability and services and alternatives to public transport. They divided the journey into pre-trip information, on-trip information, ticketing, stops and stations, vehicles and safety, reliability and service.

In the Swedish study, it was found that 20% of the population, by estimate, is having a disability. The government has proclaimed accessibility as a goal, but the legislative record is poor. It was also found that most persons with disabilities are said to prefer a car to drive themselves rather than to use public transport and prefer technical instead of human assistance if possible. In the study, it was concluded that pre-trip information needed to be improved. Regarding on-trip information and stops and stations, there was little information about accessibility. There are no special tariffs for persons with disabilities and even though many buses and trams are low-floor vehicles, some drivers did not use the kneeling function. As for safety, reliability and service, the Swedish Railway offers service for people with disabilities requiring a 24 hour notice period. Alternatives to public transport include “on demand service” which is provided by law and adaptations of private cars paid by the state government.

Within the **Euro Access Project**, funded by the EU Commission, **Ståhl and Wretstrand** (2008) studied user needs and expectations. Their goals were to review literature on the needs of disabled persons regarding accessible transport, to survey how well different user groups' needs are met and to develop a framework for mobility planning for disabled persons. Methods used were literature review and questionnaire survey.

Central theories and concepts reviewed were disability, mobility, accessibility and usability. They found that a holistic perspective is required regarding the travel chain, which should include accurate, clear and concise information, barrier-free built environment, universal design, high operational standards, intermediate solution between individual and mainstream transport option, appropriate, effective and accessible vehicle design, high levels of perceived comfort and safety and trained personnel.

Obviously needs differ between groups. Persons with mobility impairment have high requirements on physical design, for instance vehicles must be accessible and systems must be reliable. For persons with visual-, hearing-, cognitive impairment or mental health problems increased emphases is needed on information and orientation. Persons with environmental sensitivities and allergies need special attention to climate, surfaces and passenger/staff encounters. In the questionnaire survey, it was found that perceived accessibility is still low and the pricing strategies fail to meet user needs.

Ståhl and Iwarsson (2007) studied safety and accessibility for elderly persons in their local home environment. The project was divided into three phases. The first phase was also divided into three parts; a) an inquiry mailed by post to everybody living in a particular area, b) participating observation and evaluation for mapping of barriers in the environment and c) a research circle to develop an action program. In the second phase, actions were projected and implemented. The third phase included follow-up in the form of a new inquiry, participating observation and evaluation and a focus group interview. The goal with the third phase was to study changes, before and after implementation of interventions. Examples of interventions were general measures like separation of pedestrians and cyclists and selective measures like additional and better designed pedestrian crossings. Accessibility was found to increase with the actions taken. One conclusion was that small details in the environment in fact turned out to have the most crucial importance for accessibility and safety for the elderly.

<u>General conclusions in previous research and implications for further research</u>

Difficulties in measuring accessibility with a "disability lens" can be underreporting of disability (because not wanting to self-identify as disabled) or overreporting (if some benefit is seen as coming from being reported as disabled). If the goal is to find out beneficiaries of design changes, focusing on disability only can pose a problem since not only people with permanent or temporary disabilities benefit from certain changes, like inclusive design (low steps, priority seating etc), but also other people, for instance pregnant women, parents with small children, seniors, children and those with packages (Rickert, 2005). So if the goal is to compare different solutions, to see which one has the largest number of beneficiaries, focusing on people who are **"transportation disabled"** would be more adequate. According to COST (1999) accessibility barriers affect 35-49% of the population if not only persons with disabilities and elderly are taken into account but also accompanying persons, parents with baby buggies and people with luggage. This equals 170-194 million people in Europe, in other words, a large number of potential passengers.

Sometimes an access feature can be seen as an improvement of accessibility for a small group of disabled, but end up being used by everybody. An example is the kneeler feature of busses which was originally intended for older passengers and passengers with mobility problems. Bus drivers discovered that the feature improved boarding speed for all passengers, and began to kneel their vehicles at any stop. The kneeler feature is no longer thought of as a design feature for disabled passengers only, since everybody benefit from it. Therefore, even if the cost for an improvement is estimated to be high per capita, sometimes the target group benefiting can turn out to be larger than was intended from the start which makes the relative cost lower, as well as the level of “public good” higher. Other examples of low cost “inclusive design”, “universal design” or “design for all” features that everybody can benefit from, are large print destination sings or stops called out (Rickert, 2005).

Even if “Design for All” sometimes can be of low cost, it is a multidisciplinary problem and demands a co-ordinated approach. There must be an assessment of the current situation and end-users must communicate their needs. Designers must find cost-effective solutions and laboratory experiments must work in reality. End-users must validate new designs and authorities must legislate and regulate according to the findings (UNIACCESS, 2010)

According to COST, most studies up to 1999, the date of their research, found the numbers of passengers with disabilities increasing over time because of better accessibility in Europe. Another finding was that accessibility for other groups increased as well with the improvement made for the disabled as stated above. Also, the best results seemed to be obtained when many aspects of access are included, for instance design and facilities of vehicles, infrastructure, transfers at stations, information, staff training and surroundings around stations.

The World Bank (2003), states that there are significant economic costs in excluding a part of the population. In Brazil, the participation of the disabled population in the labour market is less than half of the non disabled population. The foregone earnings (without controlling for a possible sampling selection bias) are estimated to be 0,6% of the total labour income in the country. When also including the forgone earnings of the members of the household who do not work because they take care of a disabled member, another 0.8% of the observed total income has to be added (Hernández Licona, 2001). In Sweden, the situation is not as bad – in 2006 it was estimated that 67% of the disabled persons were in the labor force, compared to 80% of the non disabled (ANED, 2006). Nevertheless, if there are persons with disabilities, being prevented from work because of barriers of different kinds, it represents a cost, not only for the individual but for the country as well.

Finally, it should be noticed that today, more activities are accessible and possible to reach without transportation at all, than before - there are **mobility substitutes**. For example, it is possible to order goods and services and find information over the internet, communicate digitally, telework and use videoconferences (Litman 2003).

Competence versus Disability

In this research, not only disabilities and functional limitations will be at focus - naturally persons’ abilities will be central for the research. A key question will be how to match persons' abilities with possible new solutions in the rail transport system to improve usability and accessibility; a psychotechnical research problem. Competent behaviour is the favourable outcome for a person acting in an environmental context (Ivarsson and Ståhl, 2003).

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