MÄLARDALEN UNIVERSITY
SWEDEN

CARRIED FIRE LOAD IN MASS TRANSPORT SYSTEMS

A study of occurrence, allocation and fire behaviour of bags and luggage in metro and commuter trains in Stockholm

Mia Kumm

RESEARCH REPORT 2010:4
STUDIES IN SUSTAINABLE TECHNOLOGY

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– ENGLISH VERSION –

Abstract

A fire in an underground mass transport system is a great challenge for the fire and rescue services. The outcome of both the evacuation and the fire and rescue operation is dependent of the fire behaviour. The fire load will influence the duration of the fire and the possible damage on the construction. It will also affect the fire and rescue services' possibilities to extinguish the fire. When designing new trains high fire safety requirements are put on the carriage, the interior and the used material, but no consideration is usually taken to the carried fire load the passengers bring into the train. The fire accidents in the Baku Metro in 1995 and in the funicular railway in the Kaprun tunnel in 2000 show that the carried fire load also has a great impact on the fire. In this report the carried fire load in the Baku and Kaprun fires are discussed and the occurrence and location of carried fire load in the Stockholm mass transport systems were described. Based on the field study in Stockholm typical bags and luggage were chosen and fire test were performed at the SP Technical Research Institute of Sweden. The test includes different sizes of bags and luggage with representative contents as well as prams and shopping bags.

Introduction

Mass transport systems, such as metros, buses and commuter trains are important, but also vulnerable, links in a modern society. To liberate land for other building purposes, for example houses or apartments, many transport systems are transferred under ground. Fires in underground constructions are complex both from evacuation and rescue operation perspectives and require high standards of the rescue services, their equipment and the built-in systems for fire prevention and mitigation. Much effort was made in the last decades to raise the safety level for underground constructions. This depends on the generally raised demand on a safer society as well as on occurred fires and attacks on mass transport systems which have put focus on which consequences an underground fire can have and on the difficulties that a rescue operation in these complex environments an underground mass-transport system represents. The consequences are not only a matter of the damage on lives, property or environment, but also the disruption that a traffic hold-up in these communications would give.[1]

The higher demands has also affected the fire standards for trains and train interiors and given new classification regulations for electric cables.[2–9] A factor that is relatively uninvestigated and that in addition is difficult to control is the carried fire load the passenger's clothes, bags and luggage represent. Few systematic studies have been carried out regarding fire load and fire behavior for, for example bags and few material data can be found in the literature, while the influence from for example surfaces is better documented.[10–18] The connection between how much additional fire load this represents, the expected energy contribution and how the material affects the total fire behavior was not either earlier investigated. The fire growth has far more importance for the evacuation than maximum HRR and increased fire load, while these factors instead influence the damage on the construction and the rescue services' possibilities to perform a successful rescue operation.[19–20]

This study consist of three different parts; a study of the occurred fires in the Baku Metro in 1995[21] and in the mountain railway in Kaprun the year 2000[22–23], a field study that was carried out in the Stockholm Public Transport during the spring of 2010 and fire tests performed at SP the Swedish Technical Research Institute autumn of 2010. The project is a part of the METRO research project.[24]

Background

In a number of the occurred fires in mass transport systems under ground, left equipment, clothes and bags have made evacuation more difficult and contributed to the fire development. Due to lack of information it is difficult to determine how much left material has contributed to the fire but in two cases, the fire in the Baku[21] metro and in the mountain railway in Kaprun[22–23] there is enough information to estimate the effects of clothes, bags and equipment that were left at the evacuation.

Today very high standards are demanded for cables, seats and other furnishing[2–9] at the production of new trains as well as for loose furnishing in all public premises above and under ground[14].This report does not aim to critisise the significance of such regulations, but only to set them in proportion to the carried fire load. A brief comparison between the occurred fires in the Baku metro in Azerbaijan[21], the Daegu metro in South-Korea[24] and the fire at the Rinkeby station in the Stockholm metro in Sweden[25–26] instead shows that the choice of material in for example seats and surfaces play a very important role for fire growth and the outcome of the accident.

The fires in the Baku and Stockholm Metros

The fire in Baku, the capital of Azerbaijan, started at 5:51 pm Saturday the 28th of October 1995 in the Baku Metro. The Baku Metro has 14 underground stations, two above ground and a total length of 25,7 km. The fire started in the electrical cables in coach four in a set of five between the stations Uldus and Narimanov. At the time of the fire roughly estimated 1300–1500 persons were travelling with the train. The train moved in the direction from Uldus to Narimanov and stopped due to the fire inside the tunnel approximately 200 meters from Uldus station and 2 km from station Narimanov.[21, 27]

When the train stopped the tunnel close to the train quickly was filled with smoke, though the environment in the three first coaches was still acceptable during the approximately first ten minutes. An electric arc from the cable fire under the train burnt off the pipes to the compressor tank and the compressed air together with the electric arc quickly burnt through the floor to the coach like a welding blaze. As the pneumatic doors no longer were in function as the pipes had burnt off, the doors remained in closed position. The evacuating passengers pushed towards the doors and made them impossible to open by manual power. A couple of windows were smashed and some persons could evacuate that way, but at the same time the smoke was entering the overcrowded coaches. The assistant train-driver succeeded to open the inside connecting doors between the coaches allowing evacuation in the length direction inside the train. Only one pair of doors in coach three and the train-driver's doors at both ends of the train were open.[21, 27]

The fire in coach four made evacuation towards the nearby Uldus station more or less impossible for passengers in the three first coaches and persons evacuating down to the track instead moved towards station Narimanov. The tunnel system was equipped with mechanical ventilation and the direction of the ventilation was in the beginning of the evacuation directed from station Narimanov towards station Uldus. During the evacuation the direction of the ventilation was changed and the smoke flowed over a majority of the evacuating passengers inside the tunnel. Approximately 40 persons got killed inside the tunnel, about 25 persons inside coaches four and five and approximately 220 persons in the three first coaches. In total 289 people got killed and 265 got injured. The fire brigade saved some 70 passengers from the coaches closest to the Uldus station, although a collected fire and rescue operation could not get carried through due to lack of BA-apparatuses.[21, 27]

The coaches were of Russian E-type with chassis of steel, strengthened glass windows and doors of aluminium. The floor material was partly wood with a surface of linoleum, foam seats and laminated plastic as surface on walls and roof. The coaches had approximately 1500 kg of combustible material, which is approximately three times as much as modern coaches.[21, 27]

The accident has many similarities with the fire at the Rinkeby metro station in Stockholm 2005[25–26];

- Due to an electrical fault an electric arc underneath the train burnt off the pipes to the pneumatic system, which lead to the function of the doors being lost.
- The electric arc in combination with the escaped air created a welding blaze that burnt through the floor construction.
- It took long time before the small initial fire was discovered.
- It took relatively long time before the electric current was cut off.

There are however a number of important differences between the two fires[21, 25–27];

- The furnishing of the train was essentially different and fire development was not significantly influenced by the surface or the material of the furnishing. In the coach in Rinkeby for example several newspapers were hanging over a banister without igniting during the fire.
- The construction of the doors in Rinkeby made them possible to open in spite of the pneumatic loss and when passengers inside the coach pressed towards the doors.
- The relatively calm evacuation meant that very little carried fire load was left.

- The train at Rinkeby stopped at the platform and not inside the tunnel.
- The Fire Brigade in Stockholm had far better possibilities to perform the fire and rescue operation, both from a personnel and material resource perspective.

The mountain railway fire in Kaprun

The fire in the mountain railway in Kaprun occurred on the 11th of November 2000. The tunnel is 3,4 km long and has an inclination of 45 degrees. Prior the accident the train was described as more or less incombustible. The fire in the mountain railway train started in an electric heater placed in the lower driver's cabin. A minor leakage of hydraulic oil provided the over-heated heater with fuel and contributed to the fast fire growth in combination with melted plastic details from the driver's cabin. The oil leakage, that also supplied the train's break system, stopped the train 600 meters inside the tunnel. It also made the hydraulic driven doors impossible to open from the driver's cabin.[22–23, 28]

When the driver discovered the fire three minutes after the train turned to a halt inside the tunnel, he informed the guard at the mountain station about the fire and gets the immediate order to try to open the doors manually to save the passengers. The panic level rose among the trapped passengers and skiing boots and skis were used to try to break the windows to make evacuation possible. The train driver only succeeded to open a few doors. The fire development was very fast, partly depending on the location of the fire at the lower end of the train and the chimney effect in the tunnel, partly depending on the furnishing and left clothes and equipment.[22–23, 28]

155 people died in the fire, including the driver, one passenger in the train coming the other direction, located approximately 1200 meters from the top station, and three persons from the ski centre at the top station. Only 12 persons succeeded to get past the fire and run downwards and by that surviving the fire.[22–23, 28]

Consequences of left luggage

In both described cases the left luggage and equipment have contributed to the fire load and to some extent to the fast fire development. At the occurred accidents, due to natural reasons, measuring equipment was not present as it would be during controlled fire tests. For the Kaprun fire the left skiing equipment alone would represent a fire load of 10,5 GJ, calculating that the equipment for 161 passengers weighs 350 kg, weighted value for the heat of combustion is 30 MJ/kg as the main part of the equipment consists of plastic.[29]

After the fire in the Baku metro Swedish observers got access to the burnt train, which meant that the train and the left luggage could be documented. The photo sequence below shows how the furnishing, including the surfaces and left luggage, were affected in the totally burnt out coach 5, the, to a great extent, burnt out coach 4 and the essentially unaffected coaches 1–3. It should be noted that the fifth coach was totally burnt out, but there was still combustible material left in the fourth coach, where the fire started.[21, 27]

Pictures 1–2: The affected Baku metro coaches (5 and 4). Photo: Per Rohlén.

Pictures 3–4: The unaffected metro coaches. Photo: Per Rohlén.

The Stockholm field study

To survey the occurrence and type of carried fire load in the metro and at the commuter trains in Stockholm A field-stud was performed between the 12th of April and the 28th of May, with complementing visits in June after evaluation. The study was carried out through interviews, photo documentation and weighing of the passengers' luggage. The field study was performed in cooperation between Stockholm Transport, the tunnel operator MTR and Mälardalen University.

For the study lines, times and days were chosen so that the result would be as representative as possible for all lines in the metro and at the commuter trains at different times. At the trains random passengers were asked if they wanted to contribute to the study and allow their bags to be weighed. They were also asked what material the content consisted of, their age in ten year intervals and if they would allow the observer to take a photo of the bag. It was all registered together with the sex of the passenger, time and line. General photos were also taken to document how and where the luggage was kept during the travel. In addition it was noted what share of the passengers were carrying bags at different times.

During the study it was registered that some of the free newspapers that are distributed in the metro were left on the trains. Both for order and fire safety reasons the newspapers are continuously removed at the terminal stations. After the study it was controlled, by MTR and IL Recycling, which amount of newspapers are removed from the trains, or are placed in the METRO recycling bins at the stations. In total approximately 14 tons of paper is recycled weekly, which divided by the trains at the morning rush hours is less than 10 kg per train. The additional fire load is then in average 170 MJ per train, which can be considered negligible.

On the commuter trains the occurrence of larger bags, roller bags and suitcases was higher than on the metro, where mostly handbags, middle sized bags of sport bag type or rucksacks were carried. On the commuter trains also bikes were brought more frequently, which only occurred as an exception in the metro. The bikes do not represent any larger fire load, but were for natural reasons placed close to the exits, which influences the evacuation situation. The occurrence of prams was distributed relatively even between commuter trains and metro.

Pictures 5–8: Examples of locations for luggage, prams, bags and bicycles in the field study at Stockholm's metro and commuter trains. Photo: Moa Ankergård.

Results from the field study

In total 323 bags in the metro and 299 at the commuter trains were examined. The occurrence of suitcases and other larger bags was higher on travel days, like Fridays, Sunday afternoons and Monday mornings as well as during the business hours on Saturdays.

The average weight of each carried piece of luggage constituting a fire load at the commuter trains were

- weekdays 4,4 kg
- traveldays and weekends 4,9 kg
- in total 4,65 kg

and for metro

- weekdays 3,5 kg
- traveldays and weekends 4,5 kg
- in total 4,2 kg.

The average weight is calculated from the 323 respectively 299 weighed bags. If the average weight is calculated from the occurrence of respectively type of bag the total average weights instead are 4,5 respectively 4,1 kg. The occurrence of back-packer rucksacks can be expected to be higher during the tourist season and would then raise the average weight of the carried fire load.

On the commuter trains approximately 87% of the passengers carried bags, while the corresponding value for the metro was 82%. In average two prams were brought per train set during 75% of the studied time (rush hours and daytime). 28% of the passengers asked carried some sort of pressurized cans, like hairspray or other cans, mostly pressurized with flammable gas.

Pictures 9–13: Examples of bags in the field study at Stockholms metro/commuter trains. Photo: Moa Ankergård.

A train set in Stockholm can carry approximately 1200 passengers during rush hours. This implies that an additional fire load corresponding to 85 GJ can be present on the train. This was not accounted for when designing the trains and stations. The value was calculated with guidance of the weight distribution that was estimated during the study.

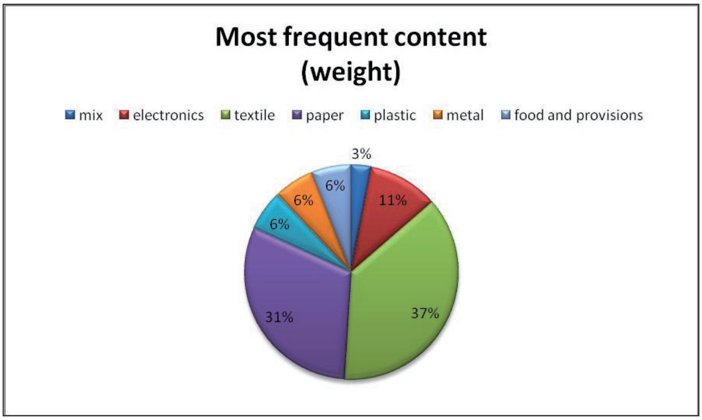

Diagram 1: Distribution of content, in total metro and commuter train.

- 1200 persons of which 82% carried a bag of 4,2 kg.
- Metal share is counted out and the rest distributed;
  - Electronics/plastic; 4133 x 0,17 x 35MJ/kg = 24 591 MJ.
  - Textile/mix; 4133 x (0,37 + 0,03) x 20MJ/kg = 33 064 MJ.
  - Paper/food; 4133 x (0,31 + 0,06) x 18MJ/kg = 27 526 MJ.

Total contribution to fire load is 85 GJ if newspapers, prams and passenger clothes, as well as possible human contribution, are excluded.

Fire tests

Based on the results from the field study 11 representative bags and one pram were chosen for further studies. The bags were packed, based on the result from the field study, and weighed. The weights were summarized in the categories metal, paper, plastic, textile, wood and other. As the study resulted in very little foundation for content of backpacker rucksacks that content instead was based on advice on backpacker homepages.[30-32] The content of the bags is separately shown in appendix 1.

The tests were carried out in following order:

1. Laptop bag.
2. Sports bag.
3. Tourist bag.
4. School bag – university.
5. School bag – high school.
6. Handbag.
7. Suitcase.
8. Cabin bag.
9. Shopping bag (clothes).
10. Backpacker rucksack.
11. Pram.

12a. Trolley bag (with food).
12b. Paper carry-bag (with food).

All tested items, except the trolley bag, ignited by the pilot flame. The food was thereafter re-packed in paper carriers and the test remade.

The weights allocated to the categories above and the measured remaining weights are shown in appendix 2.

The tests were performed in the large fire hall at the SP the Swedish Technical Research Institute, during August 2010. As ignition source a pilot flame of 25 kW LPG in 90 s was used.

Pictures 14–16: From test 4 (bag, fire test and remainders). Photo: Anna Andersson.

The test objects were placed on a grid in the safety booth underneath the measuring hood. The tests were video filmed and CO, CO_2 and O_2 as well as the temperature in the hood was measured. Calculated heat release rate (HRR) was automatically registered in the measuring program based on the measured values in the hood, while the energy content was calculated manually. HRR and energy content are shown in appendix 3 and 4. The rest weights were measured and the material distribution estimated. Both total calculated energy content and measured energy loss plus calculated rest energy content is shown. The HRR-curves for the five test objects with the highest heat release rates are shown below in diagram 2.

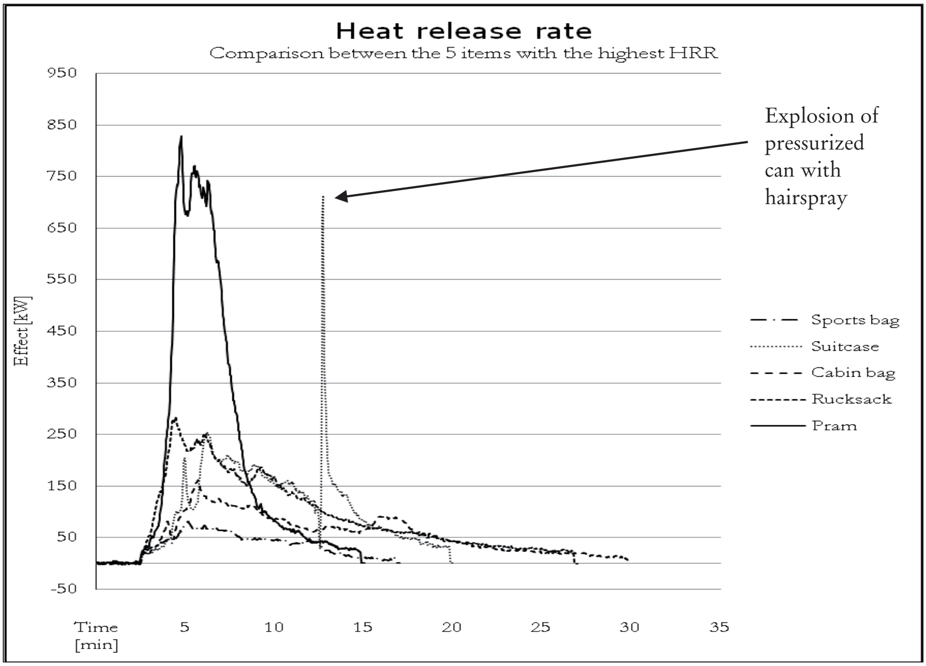

Diagram 2: Comparison between the five items with the highest HRR.

Discussion and conclusions

The performed study shows that the carried fire load in mass-transport systems under ground can be considerable, especially at rush-hours. As a comparison the new Dehli metro, built after English fire safety standards, has a dimensioning fire load of approximately 160 GJ[33], though without front cone and some of the fittings in the driver's compartment.

It shall though be noted that this train type only consists of steel passenger seats and in general have a slightly lower fire load than a train that operates in Stockholm. The carried fire load in a crowded metro train can amount to approximately 50% of the fire load of the train itself in this comparison.

In addition the fire tests show that a pram alone can be a risk to cause local flash-over in a metro coach, as it in short duration develops 831 kW. A pram will of course not self-ignite and will constitute a hazard only if it is exposed to some sort of pilot flame like arson or if it is left in the metro coach after evacuation due to fire. The pram used at the fire tests was of 2010 model and can be considered representing modern prams well. A comparison of how easily textile samples ignite between the model used at the fire tests and three other comparable models showed no marked differences.

Acknowledgement

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– SVENSK VERSION –

Sammanfattning

En brand i tåg under mark är en stor utmaning för räddningstjänsten. Såväl utrymning som räddningsinsats är beroende av hur branden utvecklas och sprids. Brandbelastningens storlek påverkar hur länge branden pågår men också räddningstjänstens möjligheter att släcka branden. Vid utformning av nya tåg ställs höga brandsäkerhetskrav på vagnar, interiör och de material som används, medan hänsyn normalt ej tas till det bagage passagerarna tar med på tåget. Brandolyckorna i Baku Metro 1995 och i bergbanan i Kapruntunneln under 2000 visade att de väskor och den utrustning passagerarna hade med på tåget hade stor betydelse för brandens förlopp. Denna rapport diskuterar bagagets betydelse vid dessa båda bränder, samt beskriver förhållandena i Stockholms tunnelbana och pendeltågsystem gällande passagerarnas bagage. Resultaten som diskuteras i rapporten bygger dels på en fältstudie utförd i Stockholm, dels på brandförsök utförda i samarbete med SP Sveriges Tekniska Forskningsinstitut. Vid brandförsöken användes väskor med vikt och innehåll baserat på den tidigare fältstudien.

Inledning

Masstransportsystem som tunnelbana, bussar och pendeltåg är viktiga, men också sårbara funktioner i ett modernt samhälle. För att frigöra mark till annan bebyggelse, exempelvis bostäder, flyttas många av dessa transportsystem ner under mark. Bränder i anläggningar under mark är komplexa ur både utrymnings och räddningsinsatsperspektiv. Det ställer höga krav på räddningstjänsten och dess utrustning och på de inbyggda system som ska förhindra att bränder uppstår eller att minska dess konsekvenser. Mycket arbete har lagts de senaste decennierna på att höja säkerheten i anläggningar under mark. Detta beror dels på det generellt höjda kravet på ett säkrare samhälle, dels på att inträffade bränder i och attentat på masstransportsystem satt fokus på vilka konsekvenser bränder under mark kan få och på svårigheterna med effektiva räddningsinsatser i den komplicerade miljö masstransportsystem under mark representerar. Konsekvenserna handlar inte bara om skador på liv, egendom och miljö, utan också på den samhällsstörning ett avbrott i sådana kommunikationer ger.[1]

De höjda kraven har också slagit igenom i och med hårdare krav på inredning i tåg och vagnar och nya krav och klassificeringsregler på elektriska kablar.[2–9] En faktor man idag vet relativt lite om och som därutöver är svår att styra är den medhavda brandbelastning som passagerarnas kläder, väskor och bagage innebär. Få systematiska studier har gjorts på brandbelastning och brandförlopp för exempelvis väskor och få säkra värden finns att hämta i litteraturen, medan exempelvis ytskiktens påverkan är bättre dokumenterad.[10–18] Kopplingen mellan hur mycket denna extra brandbelastning representerar och det förväntade bidraget i energitillskott och hur materialet bidrar till brandförloppet har heller inte tidigare kartlagts. För utrymningen har brandens tillväxthastighet större betydelse än maxeffekt och den ökade brandbelastningen, medan denna istället har betydelse för påverkan på konstruktionen och räddningstjänstens insats.[19–20]

Denna studie har innefattat tre delar: en studie av de inträffade bränderna i Bakus tunnelbana 1995[21] och i bergbanetunneln i Kaprun år 2000[22–23], en fältstudie utförd på Storstockholms lokaltrafik våren 2010 samt brandförsök utförda på SP Sveriges tekniska forskningsinstitut hösten 2010. Projektet ingår som en del i forskningsprojektet METRO.[24]

Bakgrund

I flertalet inträffade bränder i masstransportsystem under mark har kvarlämnad utrustning, kläder och väskor bidragit till att försvåra utrymningen och till brandförloppet i sig. På grund av brist på uppgifter är det svårt att avgöra hur mycket löst material bidragit under branden, men i två fall, branden i Bakus tunnelbana[21] och i bergbanebranden i Kaprun[22–23] finns information i den omfattningen att det går att uppskatta effekterna av att löst material lämnats kvar vid utrymningen.

Vid nyproduktion av tåg ställs idag mycket höga krav på kablage, säten och övrig inredning[2–9] liksom för lös inredning i övriga offentliga lokaler ovan och under mark.[14] Denna rapport avser inte att förringa betydelsen av sådana krav utan enbart att ställa dessa i proportion till den brandbelastning det medhavda bagaget innebär. En översiktlig jämförelse mellan de inträffade bränderna i Baku i Azerbaijan,[21] Daegu i Syd-Korea[24] och Rinkeby i Stockholm,[25–26] Sverige visar istället att valet av inredningsmaterial i till exempel säten och ytskikt spelar en mycket stor roll för hastigheten på brandförloppet och utgången av olyckan.

Bränderna i Bakus och Stockholms tunnelbana

Branden inträffade i Azerbaijans huvudstad Baku lördagen den 28:e oktober 1995 klockan 17:51. Tunnelbanan i Baku består av 14 stationer under jord, två ovan jord och en total sträckning om 25,7 km. Branden startade som ett elfel i vagn fyra av ett tågset om fem vagnar mellan stationerna Uldus och Narimanov. Vid olycktillfället befinner sig uppskattningsvis mellan 1300–1500 personer på tåget. Tåget går i riktning från Uldus till Narimanov och stannar på grund av branden inne i tunneln med ca 200 meter till station Uldus och ca två km till station Narimanov.[21, 27]

När tåget stannar rökfylldes tunneln i tågets närhet snabbt, dock var miljön inne i de tre första vagnarna under de första ca tio minuterna fortfarande godtagbar. Ljusbågen från kabelbranden under tåget bränner av rören till kompressortanken och luften tillsammans med ljusbågen blir som en svetslåga som snabbt bränner hål på tunnelbanevagnens golv. I och med att de pneumatiska dörrarna inte längre fungerar då rören brunnit av stannar dörrarna i stängt läge. De utrymmande personerna trycker mot dörrarna och gör det omöjligt att öppna dem med handkraft. Några fönster slås sönder vilket gör att en del lyckas att utrymma denna väg, men det gör samtidigt att röken tränger in i de överfulla vagnarna. Den biträdande lokföraren lyckas att öppna de inre förbindelse-dörrarna mellan vagnarna så att utrymning också kunde ske i tågets längdriktning. Endast ett dörrpar i vagn tre samt lokförarens dörrar i tågets båda ändar var öppna.[21, 27]

Branden i vagn fyra omöjliggjorde i stort utrymning mot den närliggande stationen Uldus för passagerare i de tre främre vagnarna och utrymmande personer som kommer ner på spåret utrymmer mot station Narimanov. Tunnelbanesystemet är försett med mekanisk ventilation och ventilationsriktningen var i utrymningens början riktad från station Narimanov mot station Uldus. Under utrymningsförloppets gång vänds ventilationsflödet och röken strömmar över flertalet av de utrymmande inne i tunneln. Ca 40 personer omkommer inne i tunneln, ett 25-tal i vagn fyra och fem samt ca 220 personer i de tre första vagnarna. Totalt omkom 289 personer och 265 skadades. Brandkåren räddade ett 70-tal passagerare från de vagnarna närmast station Uldus, dock kunde ingen samlad släck- eller räddningsinsats göras då andningsskydd saknades.[21, 27]

Vagnarna var av rysk E-typ med vagnskorg i stål, härdade glasfönster och aluminiumdörrar. Golvmaterialet mot underredet bestod delvis av trä med ett ytskikt av linoleum, säten av skumplast samt plastlaminat på väggar och tak. Dessa vagnar har ca 1500 kg brännbart material, vilket är ca tre gånger så mycket som motsvarande moderna vagnar.[21, 27]

Olyckan har många initiala likheter med branden på Rinkeby tunnelbanestation i Stockholm 2005:[25–26]

- På grund av elfel uppstod en ljusbåge under tåget som brände av tryckluftsledningarna vilket gjorde att dörrarnas funktion försvann.
- Ljusbågen tillsammans med utströmmande luft blev som en svetslåga som brände igenom trägolvskonstruktionen.
- Det tog lång tid innan den lilla initialbranden upptäcktes.
- Det tog lång tid innan elen bröts.

Det finns dock ett flertal viktiga skillnader mellan de två bränderna:[21, 25–27]

- Tågens inredning skilde sig väsentligen åt och brandförloppet inuti Rinkeby-vagnen påverkades inte nämnvärt av ytskiktet eller inredningsmaterialet. I vagnen i Rinkeby hängde till exempel Metrotidningar som inte antändes under brandförloppet.
- Dörrarnas konstruktion i Rinkeby gjorde det möjligt att öppna dem trots luftbortfallet och även då personer inne i vagnen tryckte mot utgången.
- Det relativt lugna utrymningsförloppet gjorde att mycket lite medhavt material lämnades kvar.
- Tåget i Rinkeby stod inne på perrongen och inte inne i tunneln.
- Räddningstjänsten i Stockholm hade betydligt bättre förutsättningar för en släck- och räddningsinsats, både ur ett personal- och materialresursperspektiv.

Branden i Kapruns bergbana

Branden i bergbanan i Kaprun inträffade den 11:e november år 2000. Tunneln är 3,4 km lång och i 45 graders lutning och tåget beskrevs innan olyckan som praktiskt taget obrännbart. Branden i bergbanetåget startade i ett värmeelement som placerats i den nedre förarhytten. Ett minde hydrauloljeläckage försåg det överhettade elementet med bränsle och det i kombination med att plastdetaljer i hytten smälte bidrog till det snabba brandförloppet. Oljeläckaget i systemet som också försörjde tågets bromssystem gjorde att tåget stannade 600 meter in i tunneln, men gjorde samtidigt att tågets hydrauloljedrivna dörrar inte längre kunde öppnas från förarhytten.[22–23, 28]

När förare upptäcker att det brinner tre minuter efter att tåget stannat i tunneln meddelar han vakten i bergstationen att det brinner och får då ordern att försöka att manuellt öppna dörrarna till tåget och rädda passagerarna. Paniken stiger i vagnarna bland de instängda passagerarna och pjäxor och skidor används för att försöka slå sönder fönstren och utrymma den vägen. Tågföraren lyckas endast att öppna några av dörrarna. Brandförloppet var mycket snabbt, dels beroende på initialbranden i tågets nedre ände och skorstenseffekten i den lutande tunneln, dels beroende på tågets inredning och kvarlämnade kläder och utrustning.[22–23, 28]

I branden omkom 155 människor, varav föraren och en passagerare i det mötande tåget som befinner sig ca 1200 meter från toppstationen och tre personer vid toppstationens skidcenter. Enbart 12 personer lyckades ta sig förbi branden och springa nedåt och därigenom överleva.[22–23, 28]

Betydelsen av kvarlämnat bagage

I båda de beskrivna fallen har det kvarlämnade bagaget respektive den kvarlämnade utrustningen bidragit till brandbelastningen och i viss mån det snabba brandförloppet. Vid inträffade olyckor finns av naturliga skäl inte den mätutrustning på plats, som finns tillgänglig vid kontrollerade försök. Vid branden i bergbanan i Kaprun kan dock enbart den skidutrustning som lämnades kvar i tåget för 161 personer uppskattas till 350 kg vilket motsvara ett energiinnehåll på 10,5 GJ om viktat värde för förbränningsvärmen sätts till 30 MJ/kg då huvuddelen av utrustningen består av plast.[29]

Efter branden i Bakus tunnelbana fick de svenska observatörerna tillgång till det tåg som brunnit, vilket gjorde att tåget och det kvarlämnade bagaget kunde dokumenteras. Bildserien nedan visar hur inredning inklusive ytskikt och kvarlämnat bagage påverkats i den helt utbrunna vagn 5, den till stor del utbrunna startvagnen 4 och de i princip opåverkade vagnarna 1–3. Noteras bör att vagn 5 bredvid startvagnen 4 är totalt utbrunnen medan det i startvagnen fortfarande fanns brännbart material kvar efter branden.[21, 27]

Bild 1–2: Brandutsatta vagnar vid branden i Bakus tunnelbana (5 och 4). Foto: Per Rohlén.

Bild 3–4: Opåverkade vagnar vid branden i Bakus tunnelbana. Foto: Per Rohlén.

Fältstudien i Stockholm

För att kartlägga förekomsten av och typerna av medhavt baggage på tunnelbana och pendeltåg på Storstockholms lokaltrafik genomfördes en fältstudie under perioden 12:e april till 28:e maj 2010 med kompletterande besök i juni efter utvärdering. Studien utfördes genom intervjuer, fotodokumentation och vägning av passagerarnas bagage. Fältstudien genomfördes i samarbete med Storstockholms lokaltrafik och tunneloperatören MTR Stockholm AB av studenter vid Mälardalens högskola.

För studien valdes linjer, tider och dagar så att resultatet skulle bli representativt för samtliga linjer på tunnelbana och pendeltåg vid olika tidpunkter.

På tågen blev slumpvis utvalda passagerare tillfrågade om de ville ställa upp i undersökningen och låta väga sin väska. Sedan tillfrågades de om vilket material väskan var fylld med, sin ålder i tiotal och om det gick bra att få fotografera väskan. Detta antecknades tillsammans med vilket kön passageraren hade, tid på dygnet och vilken linje det var. Det togs även översiktsbilder för att dokumentera hur och var bagaget förvaras under resan. Utöver detta noterades hur stor andel av passagerarna som medförde bagage vid olika tillfällen.

Under studien noterades att en del av de gratistidningar som delas ut i tunnelbanan lämnas på tågen. Av såväl brand- som ordningsskäl rensas dessa ut kontinuerligt vid slutstationerna. Efter studien kontrollerades, via MTR och IL Recycling, hur mycket tidningar som rensas ut, eller läggs i stationernas METRO-behållare. Totalt återvinns ca 14 ton tidningar per vecka, vilket fördelat på tåg på morgonens rusningstrafik motsvarar mindre än 10 kg tidningar/tågset. Detta innebär en tillkommande brandbelastning om i snitt 170 MJ per tåg, vilket kan anses vara försumbart.

På pendeltågen var förekomsten av stora väskor, rullväskor och resväskor större än på tunnelbanan, där huvudsakligen handväskor, mellanstora väskor modell sportbag eller ryggsäckar medfördes. På pendeltågen medfördes också cyklar, vilket endast skedde undantagsvis i tunnelbanan. Cyklarna utgör ingen större brandbelastning, men placerades av naturliga skäl oftast vid ingången, vilket påverkar utrymningssituationen. Förekomsten av barnvagnar fördelade sig relativt lika mellan tunnelbana och pendeltåg.

Bild 5–8: **Exempel på placering av bagage, barnvagnar, väskor och cyklar vid fältstudien i Stockholms tunnelbana och pendeltåg. Foto: Moa Ankergård.**

Resultat från fältstudien

Totalt kartlades 323 väskor i tunnelbanan och 299 på pendeltågen. Förekomsten av resväskor och annat större bagage var störst på resdagar som fredagar samt söndag eftermiddag och måndag morgon samt under affärernas öppettider på lördagar.

Medelvikten på varje medfört bagage för pendeltågen var

- vardagar 4,4 kg
- resdagar samt helger 4,9 kg
- totalt 4,65 kg

och för tunnelbana

- vardagar 3,5 kg
- resdagar samt helger 4,5 kg
- totalt 4,2 kg.

Medelviken är uträknad på samtliga 323 respektive 299 vägda väskor. Om medelvikten samordnas på förekomsten av respektive väsktyp blir totala medelvikten istället 4,5 respektive 4,1 kg. Det bör dock observeras att förekomsten av större ”back-packer”-ryggsäckar kan förväntas att öka under turistsäsongen och då öka medelvikten på det medhavda bagaget.

På pendeltåg medförde ca 87% av passagerarna väskor medan motsvarande siffra för tunnelbana var 82%. I snitt medfördes två barnvagnar per tågset under 75% av den studerade tiden (rusnings- och dagtid). 28% av de tillfrågade hade tryckbehållare, typ hårspray eller annan flaska trycksatt med brännbar gas.

Bild 9–13: **Exempel på väskor vid fältstudien i Stockholms tunnelbana och pendeltåg. Foto: Moa Ankergård.**

På ett tågset i Stockholms tunnelbana kan ca 1200 passagerare finnas under rusningstid. Detta innebär att en brandbelastning motsvarande 85 GJ, som vid projekteringen av brandskyddet inte medräknats, kan finnas på tåget. Siffran är framräknad med ledning av den viktfördelning som uppskattades under studien.

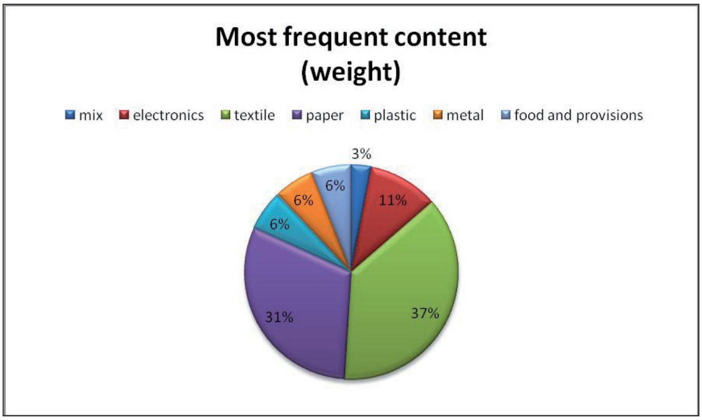

Diagram 1: Fördelning av innehåll, totalt för tunnelbana och pendeltåg.

- 1200 personer varav 82% medför ett bagage om 4,2 kg = 4133 kg
- Metallandelen räknas bort och övrigt fördelas:
    - Elektronik/plast; 4133 x 0,17 x 35MJ/kg = 24 591 MJ
    - Textil/mix; 4133 x (0,37 + 0,03) x 20MJ/kg = 33 064 MJ
    - Papper/matv.; 4133 x (0,31+0,06) x 18MJ/kg = 27 526 MJ.

Totalt tillskott på brandbelastningen blir då 85 GJ om tidningar, barnvagnar och passagerarnas kläder, liksom eventuellt mänskligt tillskott, försummas.

Brandförsök

Utifrån resultaten från fältstudien valdes 11 representativa väskor och en barnvagn ut för brandförsök. Väskorna packades, baserat på resultatet från studien, och vägdes. Vikterna sammanställdes i kategorierna metall, papper, plast, textil, trä och övrigt. Då mycket litet underlag från studien visade back-packer ryggsäckars innehåll bestämdes detta innehåll med ledning från informationssidor och packningsråd för backpackers.[30–32] Väskornas innehåll redovisas separat i bilaga 1.

Testerna utfördes i följande ordning:

1. Dataväska.
2. Sportbag.
3. Turistväska.
4. Skolväska högskola.
5. Skolväska gymnasiet.
6. Handväska.
7. Resväska.
8. Kabinväska.
9. Shoppingkasse (kläder).
10. Backpacker-ryggsäck.
11. Barnvagn.

12a. ”Dramaten” (med mat).
12b. Kassar (med mat).

Samtliga tester gick till fullt utvecklad brand utom rullväskan ”Dramaten”, som ej antändes av pilotlågan. Maten packades då om i papperskassar och försöket gjordes om.

Vikterna fördelat på kategorier enligt ovan samt restvikter redovisas i bilaga 2.

Testerna utfördes i stora brandhallen på SP Sveriges tekniska forskningsinstitut under augusti 2010. Som tändkälla användes en pilotlåga med gasol om 25 kW i 90 s.

Bild 14–16: **Från test 4 (väska, brandtest och rester). Foto: Anna Andersson.**

Försöksföremålen placerades på ett galler i skyddsburen under mäthuven. Försöken videofilmades och CO, CO_2 samt O_2 och temperatur i huven mättes. Beräknat heat release rate (HRR) registrerades automatiskt i mätprogrammet utifrån de uppmätta värdena medan energiinnehållet beräknades manuellt. HRR och energiinnehåll redovisas i bilaga 3 och 4. Restvikterna noterades och materialfördelningen uppskattades. Både totalt beräknat energiinnehåll och uppmätt energiförlust plus beräknad restenergi redovisas. Effektkurvorna för de fem testobjekt med de högsta effekterna finns sammanställda nedan i diagram 2.

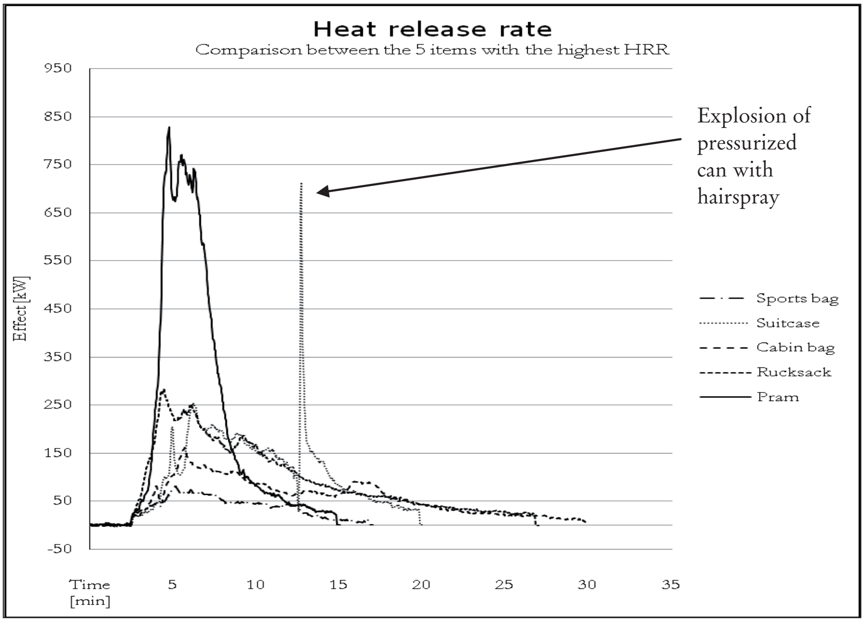

Diagram 2: Jämförelse mellan de fem föremålen med störst värmeutveckling.

Diskussion och slutsatser

Den genomförda studien visar att den medhavda brandbelastningen i masstransportsystem under mark kan, vara betydande, speciellt vid rusningstrafik.

Som jämförelse har exempelvis den nya tunnelbanan i Dehli, byggd efter engelska brandsäkerhetskrav, ca 160 GJ[33] i dimensionerande brandbelastning, dock utan noskåpa och viss förarhyttsinredning. Det skall noteras att denna typ av tåg endast innehåller passagerarsäten av stål och generellt sett har en något lägre brandbelastning än de vagnar som idag trafikerar Stockholm. Den medhavda brandbelastningen i ett fullsatt tunnelbanetåg kan i denna jämförelse då uppgå till ca 50% av själva tågets brandbelastning.

Utöver detta visar brandförsöken att en barnvagn ensamt kan utgöra en risk för en tunnelbanevagn går till lokal övertändning, då den kortvarigt utvecklar 831 kW. En barnvagn kommer naturligtvis inte att självantända utan utgör en fara först då den utsätts för någon typ av pilotlåga, exempelvis vid en anlagd brand eller om den lämnas kvar i tunnelbanevagnen vid en utrymningssituation vid brand. Barnvagnen som användes vid försöken var av 2010 års modell och kan anses representera dagens barnvagnar väl. En jämförelse av antändligheten mellan tygprover från den modell som användes vid försöken och tre andra jämförbara modeller visade inga markanta skillnader.

Tack till…

Författaren vill rikta ett stort tack till de personer som har gjort denna studie möjlig. Praktikant Moa Ankergård som tillbringade veckor av sin LIA-praktik ombord på pendel- och tunnelbanetåg i Stockholm. Alla hjälpsamma passagerare som tillät bagaget att bli vägt och undersökt – Moa fick bara skäll en enda gång. Studenterna Anna Andersson och Eva-Sara Carlsson som packade och vägde alla väskor och släpade dem på tåget till Borås, assisterade vid brandförsöken, tog observatörsanteckningar och hjälpte till med foton och siffror. Brandteknikerna på SP för ovärderlig hjälp med brandtesterna. Anders Carlsson och Rolf Åkerstedt på SL Storstockholms lokaltrafik för hjälp att arrangera fältstudien. Tunneloperatören MTR för hjälp med tillstånd och dokumentation av kvarlämnade tidningar. Sist men inte minst vill också författaren tacka de organisationer som skänkte material till brandtesterna och METRO-projektets finansiärer; SL, Trafikverket, Fortifikationsverket, Myndigheten för samhällsskydd och beredskap, FORMAS och Brandforsk.

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APPENDICES/BILAGOR

Appendix 1: Specification of content in tested objects

In this appendix the contents of the bags are presented. The contents are divided into groups; electronics, metal, textile, paper, plastic and wood. For each group a detailed list of weights are shown.

Test 1: Computer bag

1.1 Electronics

Picture 1: Computer bag; computer, chargers and mouse

Content	Weight [kg]
Computer	2,150
Charger (computer)	0,420
Mouse	0,114
Charger (cell phone)	0,208
Total	**2,904**

Table 1: Computer bag – total content of electronics

1.2 Textile

Picture 2: Computer bag; bag

Content	Weight [kg]
Computer bag	2,664
Total	**2,664**

Table 2: Computer bag – total content of textile

1.3 Paper

Picture 3: Computer bag; folder, note pad and re-

Content	Weight [kg]
Note pad	0,354
Folder	0,176
Report	0,198
Total	**0,728**

Table 1: Computer bag – total content of paper

1.4 Plastic

Picture 4: Computer bag; pens

Content	Weight [kg]
Pens	0,034
Total	**0,034**

Table 4: Computer bag – total content of plastic

1.5 Compilation

Material	Weight [kg]	Proportion [%]
Electronics	2,904	46
Textile	2,664	42
Paper	0,728	12
Plastic	0,034	1
Total	**6,330**	**100**

Table 5: Computer bag – compilation

Test 2: Sports bag

2.1 Textile

Picture 5: Sports bag; bag

Picture 6: Sports bag; clothes (polyester)

Picture 7: Sports bag; clothes (cotton)

Content	Weight [kg]
Clothes (cotton)	1,324
Clothes (polyester)	0,410
Bag	0,676
Total	**2,410**

Table 6: Sports bag – total content of textile

2.2 Plastic

Picture 8: Sports bag; water bottle

Picture 9: Sports bag; tennis balls

Picture 10: Sports bag; toilet requsites

Picture 11: Sports bag; training shoes

Content	Weight [kg]
Training shoes	0,532
Water bottle	0,052
Shampoo 250 ml	0,274
Conditioner 200 ml	0,220
Soap 50 ml	0,066
Tennis balls	0,114
Total	**1,258**

Table 7: Sports bag – total content of plastic

2.3 Wood

Picture 12: Sports bag; tennis racket

Content	Weight [kg]
Racket	0,184
Total	**0,184**

Table 8: Sports bag – total content of wood

2.4 Compilation

Material	Weight [kg]	Proportion [%]
Textile	2,410	63
Plastic	1,258	33
Wood	0,184	4
Total	**3,852**	**100**

Table 9: Sports bag – compilation

Test 3: Tourist bag

3.1 Textile

Picture 13: Tourist bag: bag

Picture 14: Fleece jacket and camera case

Content	Weight [kg]
Bag	0,312
Fleece jacket	0,418
Camera case	0,024
Total	**0,754**

Table 10: Tourist bag – total content of textile

3.2 Plastic

Picture 15: Tourist bag; water bottle, rain coat, sitting pad and sticking plaster

Content	Weight[kg]
Rain coat	0,346
Water bottle	0,070
Sitting coat	0,018
Sticking Plaster	0,022
Plastic bag	0,062
Total	**0,518**

Table 11: Tourist bag – total content of plastic

3.3 Electronics

Picture 16: Tourist bag; camera, cell phone and charger (cell-phone)

Content	Weight [kg]
Camera	0,126
Cell phone	0,070
Charger (cell phone)	0,180
Total	**0,376**

Table 12: Tourist bag – total content of electronics

3.4 Paper

Picture 17: Tourist bag; tourist handbook and map

Content	Weight [kg]
Tourist handbook	0,106
Map	0,380
Total	**0,486**

Table 13: Tourist bag – total content of paper

3.5 Compilation

Material	Weight [kg]	Proportion [%]
Textile	0,754	35
Plasticic	0,518	24
Electronics	0,376	18
Paper	0,486	23
Total	**2,134**	**100**

Table 14: Tourist bag; compilation

4 Test 4: School bag – university

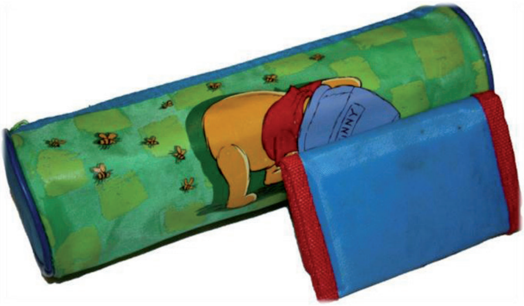
4.1 Textile

Picture 18: School bag – university; bag

Content	Weight [kg]
Bag	0,312
Total	**0,312**

Table 15: School bag – university – total content of textile

4.2 Plastic



Picture 19: School bag – university; wallet withholding credit cards and pencil case with pencils, rubbers and a ruler

Picture 20: School bag – university; calendar

Content	Weight [kg]
Rubber	0,014
Calendar	0,078
Pencil case	0,030
Ruler	0,012
Pencils	0,046
Credit cards	0,020
Wallet	0,026
Total	**0,226**

Table 16: School bag – university – total content of plastic

4.3 Paper

Picture 21: School bag – university; binder, books and a note pad

Content	Weight [kg]
Binder	2,158
Books	1,942
Note pad	0,364
Total	**4,464**

Table 17: School bag – university – total content of paper

4.4 Electronics

Picture 22: School bag – university; computer, charger (computer), calculator, cell phone, charger (cell phone), headset and USB memory stick

Content	Weight [kg]
Computer	2,150
Charger (computer)	0,520
Calculator	0,152
Cell phone	0,100
Headset	0,014
Charger (cell phone)	0,066
USB memory stick	0,016
Total	**3,018**

Table 18: School bag – university – total content of electronics

4.5 Compilation

Material	Weight [kg]	Proportion [%]
Textile	0,312	4
Plastic	0,226	3
Paper	4,464	56
Electronics	3,018	38
Total	**8,020**	**100**

Table 19: School bag – university – compilation

5 Test 5: School bag – high school

5.1 Textile

Picture 23: School bag – high school; bag

Content	Weight [kg]
Bag	0,346
Total	**0,346**

Table 20: School bag – high school – total content of textile

5.2 Plastic

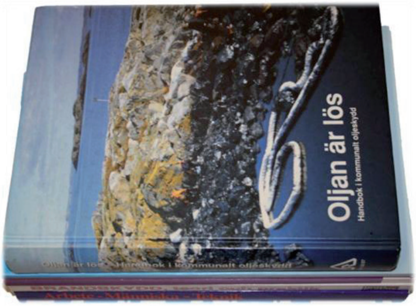
Picture 24: School bag – high school; pencil case with pencils, rubber and roller

Picture 25: School bag – high school; calendar

Content	Weight [kg]
Pencil case	0,030
Rubber	0,014
Roller	0,012
Calendar	0,074
Pencils	0,460
Total	**0,590**

Table 21: School bag – high school – total content of plastic

5.3 *Paper*



Picture 26: **School bag – high school; books and note pad**

Content	Weight [kg]
Books	4,142
Note pad	0,364
Total	**4,506**

Table 22: **School bag – high school – total content**

5.4 *Electronics*

Picture 27: **School bag – high school; calculator and cell phone**

Content	Weight [kg]
Calculator	0,098
Cell phone	0,07
Total	**0,168**

Table 23: **School bag – high school – total content of electronics**

5.5 *Compilation*

Material	Weight [kg]	Proportion [%]
Textile	0,346	6
Plastic	0,590	11
Paper	4,506	80
Electronics	0,168	3
Total	**5,610**	**100**

Table 24: **School bag – high school – compilation**

6 Test 6: Handbag

6.1 Textile

Picture 28: Handbag; bag

Picture 29: Handbag; scarf

Picture 30: Handbag; key band

Content	Weight [kg]
Key band	0,026
Bag	0,350
Scarf	0,204
Total	**0,580**

Table 25: Handbag – total content of metal

6.2 Plastic and metal

Picture 31: **Handbag; wallet, pen and umbrella**

Content	Weight [kg]
Wallet	0,104
Pen	0,008
Umbrella	0,276
Chap stick	0,012
Hand cream 25 ml	0,030
Disinfectant 50 ml*	0,062
Credit cards	0,024
Total	**0,516**

* Contains alcohol 50 ml

Table 26: Handbag – total content of plastic

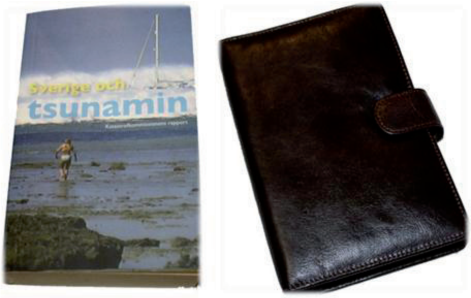
Picture 32: Handbag; chap stick, hand cream, disinfectant and hairspray

Content	Weight [kg]
Hairspray 75 ml	0,080
Total	**0,080**

* Contains butane (quantity not stated on container)

Table 27: Handbag – total content of metal

6.3 Paper



Picture 33: Handbag; book and calendar

Content	Weight [kg]
Calendar	0,454
Book	0,264
Total	**0,718**

Table 28: Handbag – total content of paper

6.4 Electronics

Picture 34: Handbag; cell phone, charger (cell phone), headset and bank security device

Content	Weight [kg]
Cell phone	0,076
Charger (cell phone)	0,064
Headset	0,020
Bank device	0,026
Total	**0,186**

Table 29: Handbag – total content of electronics

6.5 Compilation

Material	Weight [kg]	Proportion [%]
Textile	0,580	28
Plastic	0,516	25
Paper	0,718	35
Electronics	0,186	9
Metal	0,080	4
Total	**2,080**	**100**

Table 30: Handbag – compilation

7 Test 7: Suitcase

7.1 Plastic and metal

Picture 35: Suitcase; bag and vanity bag

Picture 36: Suitcase; plastic bags

Picture 37: Suitcase; shoes

Content	Weight [kg]
Bag	4,254
Shoes	0,136
Vanity bag	0,046
Sun lotion 50 ml	0,060
After sun 200 ml	0,206
Shampoo 250 ml	0,276
Deodorant 60 ml *	0,100
Toothbrush	0,010
Chap stick	0,024
Soap and soapbox	0,028
Total	**5,140**

* Contains alcohol
(quantity not stated on container)

Table 31: Suitcase – total content of plastic

Picture 38: Suitcase; toilet requisites and hairspray

Content	Weight [kg]
Toothpaste 20 ml	0,028
Hairspray 400 ml*	0,392
Total	**0,420**

* Contains butane (quantity not stated on container)

Table 32: Suitcase – total content of metal

7.2 Textile

Picture 39: Suitcase; swimwear

Picture 40: Suitcase; clothes

Content	Weight [kg]
Clothes (cotton)	7,914
Shoes (ballerina)	0,278
Shoes (Sneakers)	0,438
Swimwear	0,104
Total	**8,734**

Table 33: Suitcase – total content of textile

7.3 Paper

Picture 41: Suitcase; books

Content	Weight [kg]
Pocket (2)	0,208
Cardboard box	0,034
Total	**0,242**

Table 34: Suitcase – total content of paper

7.4 Electronics

Picture 42: Adapter and charger (cell phone)

Content	Weight [kg]
Charger (cell phone)	0,068
Adapter	0,124
Total	**0,192**

Table 35: Suitcase – total content of electronics

7.5 Compilation

Material	Weight [kg]	Proportion [%]
Plastic	5,140	35
Textile	8,734	59
Paper	0,242	2
Metal	0,420	3
Electronic	0,192	1
Total	**14,728**	**100**

Table 36: Suitcase – compilation

8 Test 8: Cabin bag

8.1 Plastic

Picture 43: Cabin bag; bag and shoes

Picture 44: Cabin bag; toilet requisites

Content	Weight [kg]
Bag	3,614
Shoes	0,852
Shampoo 30 ml*	0,040
Conditioner 30 ml*	0,038
Soap 50 ml	0,064
Deodorant 60 ml*	0,098
Safety razor (2)	0,012
Medicine	0,004
Total	**4,466**

* Contains alcohol

Table 37: Cabin bag – total content of plastic

8.2 Textile

Picture 45: Cabin bag; clothes

Picture 46: Cabin bag; vanity bag

Content	Weight [kg]
Clothes (cotton)	3,446
Vanity bag	0,172
Total	**3,446**

Table 38: Shopping bag – total content textile

8.3 *Paper*

Picture 47: Cabin bag; paper and book

Content	Weight [kg]
Book	0,114
Paper	0,078
Total	**0,192**

Table 39: Cabin bag – total content of paper

8.4 *Compilation*

Material	Weight [kg]	Proportion [%]
Paper	0,192	2
Plastic	4,466	49
Textile	4,396	49
Total	**9,054**	**100**

Table 40: Cabin bag – compilation

9 Test 9: Shopping bag

9.1 Textile

Picture 48: Shopping bag; clothes

Content	Weight [kg]
Clothes (cotton)	3,446
Total	**3,446**

Table 41: Shopping bag – total content textile

9.2 Plastic

Picture 49: Shopping bag; plastic bag

Content	Weight [kg]
Plastic bag	0,044
Coat hanger	0,146
Total	**0,190**

Table 42: Shopping bag – total content plastic

9.3 Compilation

Material	Weight [kg]	Proportion [%]
Plastic	0,190	5
Textile	3,446	95
Total	**3,636**	**100**

Table 43: Shopping bag – compilation

10 Test 10: Rucksack

10.1 Textile

Picture 50: Rucksack; bag

Picture 51: Rucksack; clothes and swimwear

Picture 52: Rucksack; pillow

Picture 53: Rucksack; towel

Picture 54: Rucksack; sleeping bag

Picture 55: Rucksack; vanity bag and eye patch

Content	Weight [kg]
Bag	2,778
Sleeping bag	1,578
Towel	0,238
Pillow	0,268
Swimwear	0,180
Jumper (2)	3,984
Trousers (2)	0,000
Shorts (2)	0,000
Skirt (3)	0,000
T-shirt (4)	0,000
Linen (3)	0,000
Under wear (3)	0,000
Socks (2)	0,000
Vanity bag	0,116
Eye patch	0,010
Total	**9,152**

Table 44: Rucksack – total content of textile

10.2 Plastic

Picture 56: Rucksack; rain suit, shoes and pens

Picture 57: Rucksack; water bottle and toilet requisites

Content	Weight [kg]
Plastic front cover	0,018
Shoes (flip-flop)	0,168
Shoes (ballerina)	0,144
Rain suit	0,466
Shampoo 48ml	0,062
Conditioner 49ml	0,060
Lotion 50ml	0,050
Toothbrush kit 25g	0,042
Medicine	0,056
Sticking plaster	0,006
Disinfectant 50ml*	0,056
Moist napkin	0,070
Ear plugs	0,001
Pens	0,012
Water bottle	0,066
Total	**1,277**

* Contains alcohol

Table 45: Rucksack – total content of plastic

10.3 Paper

Picture 58: Rucksack; books, maps and tourist handbooks

Picture 59: Rucksack; a pack of cards and a Sudoku book

Content	Weight [kg]
Tourist handbook (2)	1,148
Maps	0,076
Books (2)	0,254
Travel logbook	0,186
A pack of cards	0,078
Sudoku book	0,046
Total	**1,788**

Table 46: Rucksack – total content of paper

10.4 Electronics

Picture 60: Rucksack; charger (cell phone) and flash light

Content	Weight [kg]
Flash light	0,104
Charger (cell phone)	0,158
Total	**0,262**

Table 47: Rucksack – total content of electron-

10.5 Compilation

Material	Weight [kg]	Proportion [%]
Electronics	0,262	2
Paper	1,788	14
Plastic	1,277	10
Textile	9,152	73
Total	**12,479**	**100**

Table 48: Rucksack – compilation

11 Test 11: Pram

11.1 Textile

Picture 61: Pram; pillow and blanket

Picture 62: Pram (scrambled picture)

Content	Weight [kg]
Pram	4,122
Under basket	0,330
Bed sheets	0,542
Blanket	0,394
Pillow	0,286
Cover	0,108
Total	**5,782**

Table 49: Pram – total content of textile

11.2 Plastic

Content	Weight [kg]
Tire (4)	3,640
Rain cover	0,196
Total	**3,836**

Table 50: Pram – total content of plastic

11.3 Metal

Content	Weight [kg]
Frame	5,490
Total	**5,490**

Table 51: Pram – total content of metal

11.4 Compilation

Material	Weight [kg]	Proportion[%]
Metal	5,490	36
Plastic	3,836	25
Textile	5,782	38
Total	**15,108**	**100**

Table 52: Pram – compilation

12 Test 12: Food bags

Picture 63: Food bags; food

Picture 64: Food bags; food

Content	Weight [kg]
Plastic bag	0,016
Plastic wrapping	0,211
Total	**0,227**

Table 53: Food bags – total content of plastic

Content	Weight [kg]
Paper bag	0,066
Paper wrapping	0,839
Total	**0,905**

Table 54: Food bags – total content of paper

Content	Weight [kg]
Metal	0,018
Total	**0,018**

Table 55: Food bags – total content of metal

Content	Weight [kg]
Glass	0,410
Total	**0,410**

Table 56: Food bags – total content of glass

12.1 Compilation

Material	Weight [kg]	Proportion [%]
Food	6,172	80
Paper	0,905	12
Plastic	0,227	3
Metal	0,018	0
Glass	0,410	5
Total	**7,732**	**100**

Table 57: Food bags – compilation

Appendix 2: Inventory of weights and material distribution before and after fire test

Test 1: Computer bag

Before the fire test

Test 1: Computer bag		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	2,904	46
Textile	2,664	42
Paper	0,728	12
Plastic	0,034	1
Total	**6,330**	**100**

Table 1: Weight for the computer bag before the fire test

After the fire test

Test 1: Computer bag		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	2,629	65
Textile	0	0
Paper	0,500	12
Plastic	0,900	22
Total	**4,029**	**100**

Table 2: Weight for the computer bag after the fire test

Test 2: Sports bag

Before the fire test

Test 2: Sports bag		
Material	**Weights [kg]**	**Proportion [%]**
Textile	2,410	63
Plastic	1,258	33
Wood	0,184	5
Total	**3,852**	**100**

Table 3: Weight for the sports bag before the fire test

After the fire test

Test 2: Sports bag		
Material	**Weights [kg]**	**Proportion [%]**
Textile	0,892	75
Plastic	0,250	21
Wood	0,040	3
Total	**1,182**	**100**

Table 4: Weight for the sports bag after the fire test

Test 3: Tourist bag

Before the fire test

Test 3: Tourist bag		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	0,376	18
Textile	0,754	35
Paper	0,486	23
Plastic	0,518	24
Total	**2,134**	**100**

Table 5: Weight for the tourist bag before the fire test

After the fire test

Test 3: Tourist bag		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	0,222	25
Textile	0,100	11
Paper	0,180	20
Plastic	0,400	44
Total	**0,902**	**100**

Table 6: Weight for the tourist bag after the fire test

Test 4: School bag – university

Before the fire test

Test 4: School bag – university		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	3,018	38
Textile	0,312	4
Paper	4,464	56
Plastic	0,226	3
Total	**8,020**	**100**

Table 7: Weight for the school bag before the fire test

After the fire test

Test 4: School bag – university		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	2,800	38
Textile	0	0
Paper	4,448	61
Plastic	0,100	1
Total	**7,348**	**100**

Table 8: Weight for the school bag after the fire test

Test 5: School bag – high school

Before the fire test

Test 5: School bag – high school		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	0,168	3
Textile	0,346	6
Paper	4,506	80
Plastic	0,590	11
Total	5,610	100

Table 9: Weight for the school bag before the fire test

After the fire test

Test 5: School bag – high school		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	0,200	4
Textile	0	0
Paper	4,618	94
Plastic	0,110	2
Total	4,928	100

Table 10: Weight for the school bag after the fire test

Test 6: Handbag

Before the fire test

Test 6: Handbag		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	0,186	9
Textile	0,580	28
Paper	0,718	35
Plastic	0,516	25
Metal	0,080	4
Total	**2,080**	**100**

Table 11: Weight for the handbag before the fire test

After the fire test

Test 6: Handbag		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	0,300	19
Textile	0,300	19
Paper	0,700	44
Plastic	0,200	13
Metal	0,077	5
Total	**1,577**	**100**

Table 12: Weight for the handbag after the fire test

Test 7: Suitcase

Before the fire test

Test 7: Suitcase		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	0,192	1
Textile	8,734	59
Paper	0,242	2
Plastic	5,140	35
Metal	0,420	3
Total	**14,728**	**100**

Table 13: Weight for the suitcase before the fire test

After the fire test

Test 7: Suitcase		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	0,200	2
Textile	9,641	87
Paper	0,330	3
Plastic	0,770	7*
Metal	0,100	1
Total	**11,041**	**100**

** 0,67 kg metal from the suitcase*

Table 14: Weight for the suitcase after the fire test

Test 8: Cabin bag

Before the fire test

Test 8: Cabin bag		
Material	**Weights [kg]**	**Proportion [%]**
Textile	4,396	49
Paper	0,192	2
Plastic	4,466	49
Total	9,054	100

Table 15: Weight for the cabin bag before the fire test

After the fire test

Test 8: Cabin bag		
Material	**Weights [kg]**	**Proportion [%]**
Textile	6,519	90
Paper	0,300	4
Plastic	0,400	6*
Total	7,219	100

** Metal from the bag*

Table 16: Weight for the cabin bag after the fire test

Test 9: Shopping bag

Before the fire test

Test 9: Shopping bag		
Material	**Weights [kg]**	**Proportion [%]**
Textile	3,446	95
Plastic	0,190**	5
Total	**3,636**	**100**

Table 17: Weight for the shopping bag before the fire test

After the fire test

Test 9: Shopping bag		
Material	**Weights [kg]**	**Proportion [%]**
Textile	3,446*	97
Plastic	0,100**	3
Total	**3,546**	**100**

** Only smoldering fire therefore much remaining textile*
*** 0,5 kg metal not involved in fire and not accounted for (clothes-hanger details)*

Table 18: Weight for the shopping bag after the fire test

Test 10: Rucksack

Before the fire test

Test 10: Rucksack		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	0,262	2
Textile	9,152	73
Paper	1,788	14
Plastic	1,277	10
Total	**12,479**	**100**

Table 19: Weight for the rucksack before the fire test

After the fire test

Test 10: Rucksack		
Material	**Weights [kg]**	**Proportion [%]**
Electronics	0,200	2*
Textile	8,267	77**
Paper	1,800	17
Plastic	0,500	5
Total	**10,767**	**100**

** 0,1 kg metal*
** *1,5 kg metal from the bag*

Table 20: Weight for the rucksack after the fire test

Test 11: Pram

Before the fire test

Test 11: Pram		
Material	**Weights [kg]**	**Proportion [%]**
Textile	5,782	38
Plastic	3,836	25
Metal	5,490	36
Total	**15,108**	**100**

Table 21: Weight for the pram before the fire test

After the fire test

Test 11: Pram		
Material	**Weights [kg]**	**Proportion [%]**
Textile	0,500	6
Plastic	0,203	2
Metal	7,500	91
Total	**8,203**	**100**

Table 22: Weight for the pram after the fire test

Test 12a: Trolley bag ("dramaten")

Before the fire test

Test 12a: Trolley bag		
Material	**Weights [kg]**	**Proportion [%]**
Paper	0,839	9
Plastic	1,007	10
Metal	1,370	14
Glas	0,410	4
Food	6,172	63
Total	**9,798**	**100**

Table 23: Weight for the trolley bag before the fire test

After the fire test

Test 12a: Trolley bag		
Material	**Weights [kg]**	**Proportion [%]**
Paper	x	x
Plastic	x	x
Metal	x	x
Glas	x	x
Food	x	x
Total	**x***	**x***

** Data missing as the test was aborted*

Table 24: Weight for the trolley bag after the fire test

Test 12b: Food bags

Before the fire test

Test 12b: Food bags		
Material	**Weights [kg]**	**Proportion [%]**
Paper	0,905	12
Plastic	0,227	3
Metal	0,018	0
Glas	0,410	5
Food	6,172	80
Total	**7,732**	**100**

Table 25: Weight for the food bags before the fire test

After the fire test

Test 12b: Food bags		
Material	**Weights [kg]**	**Proportion [%]**
Paper	0	0
Plastic	0	0
Metal	0	0
Glas	0	0
Food	7,707	100
Total	**7,707**	**100**

Table 26: Weight for the food bags after the fire test

Appendix 3: Heat Release Rate (HRR) for tested objects

Total HRR for test 1: Computer bag

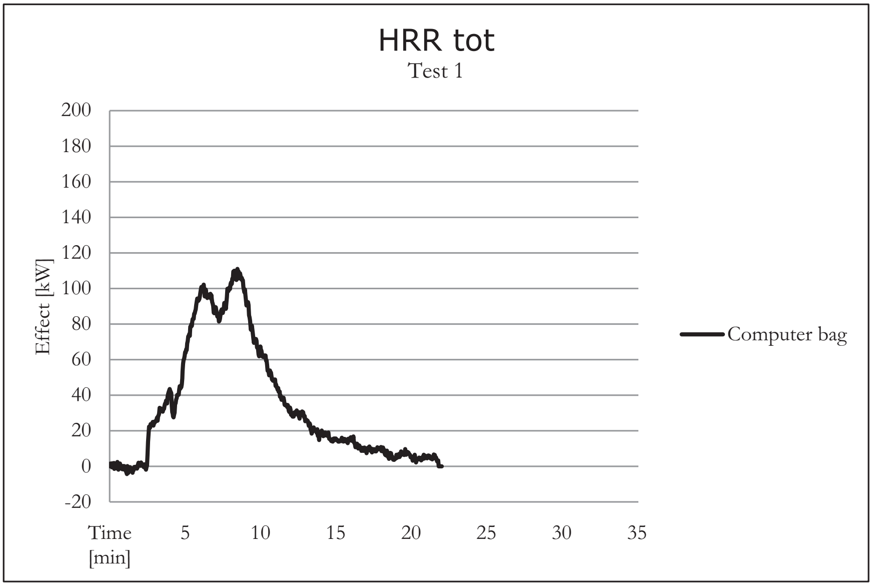


Diagram 1: Total Heat Release Rate for test 1: computer bag

Total HRR for test 2: Sports bag

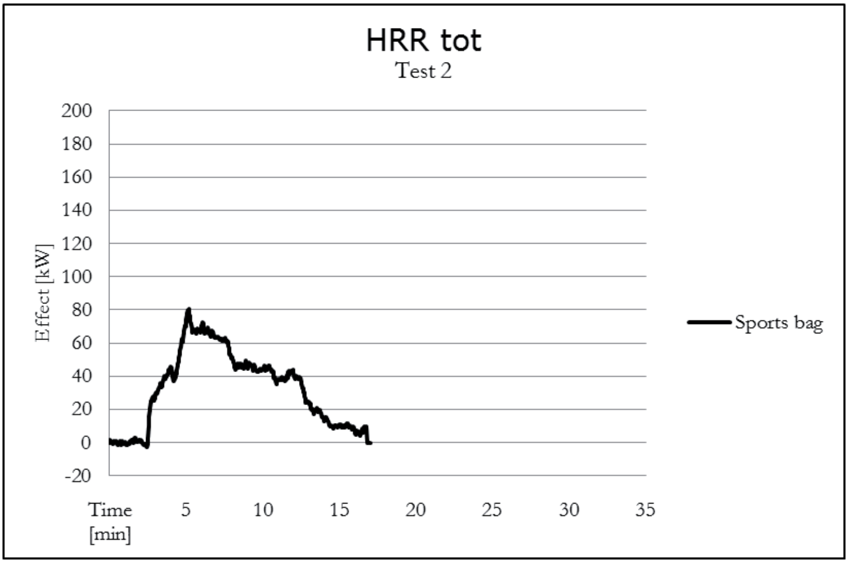


Diagram 2: Total Heat Release Rate for test 2: sports bag

Total HRR for test 3: Tourist bag

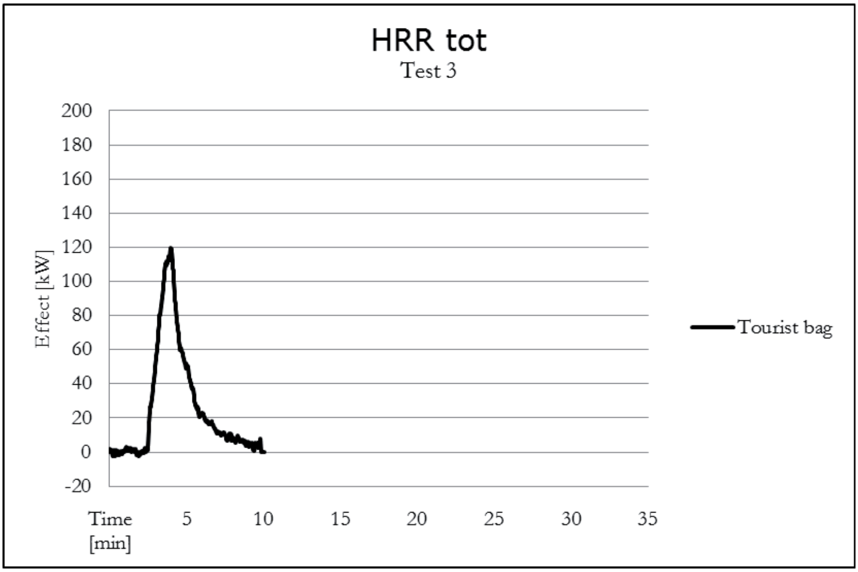


Diagram 3: Total Heat Release Rate for test 3: tourist bag

Total HRR for test 4: School bag – university

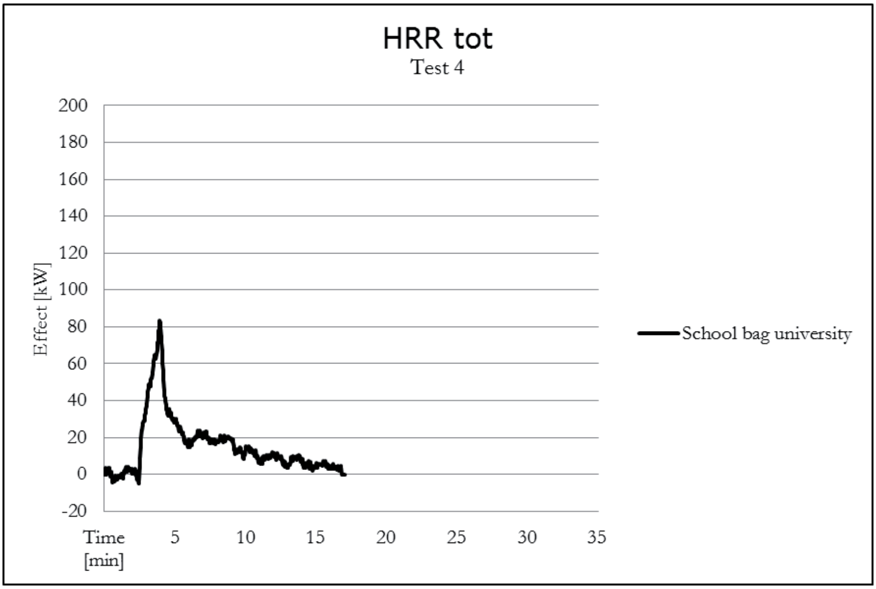


Diagram 4: Total Heat Release Rate for test 4: school bag – university

Total HRR for test 5: School bag – high school

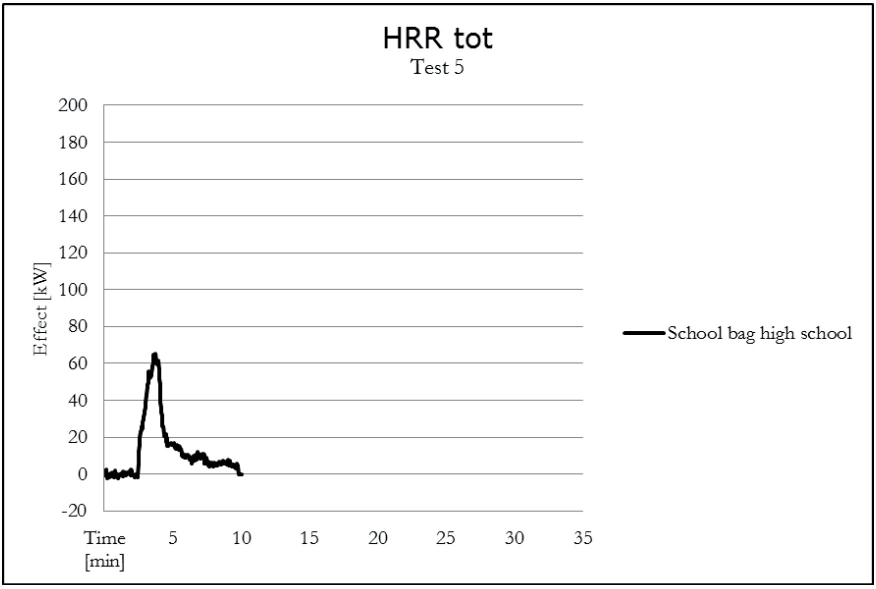


Diagram 5: Total Heat Release Rate for test 5: school bag – high school

Total HRR for test 6: Hand bag

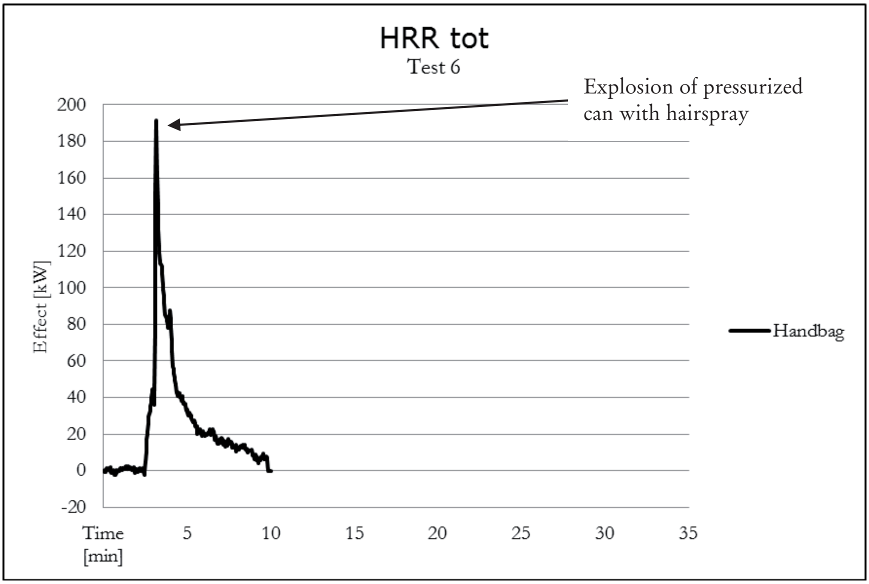


Diagram 6: Total Heat Release Rate for test 6: handbag

Total HRR for test 7: Suitcase

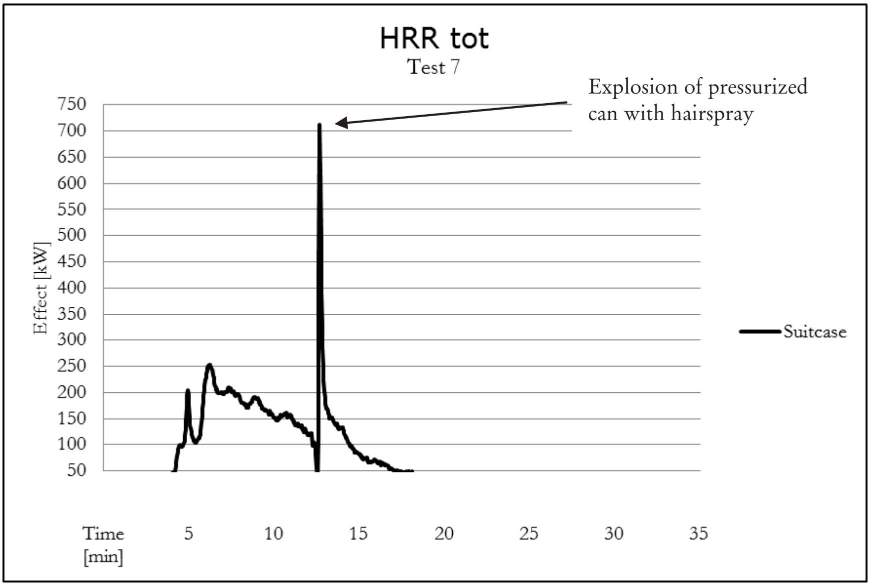


Diagram 7: Total Heat Release Rate for test 7: suitcase

Total HRR for test 8: Cabin bag

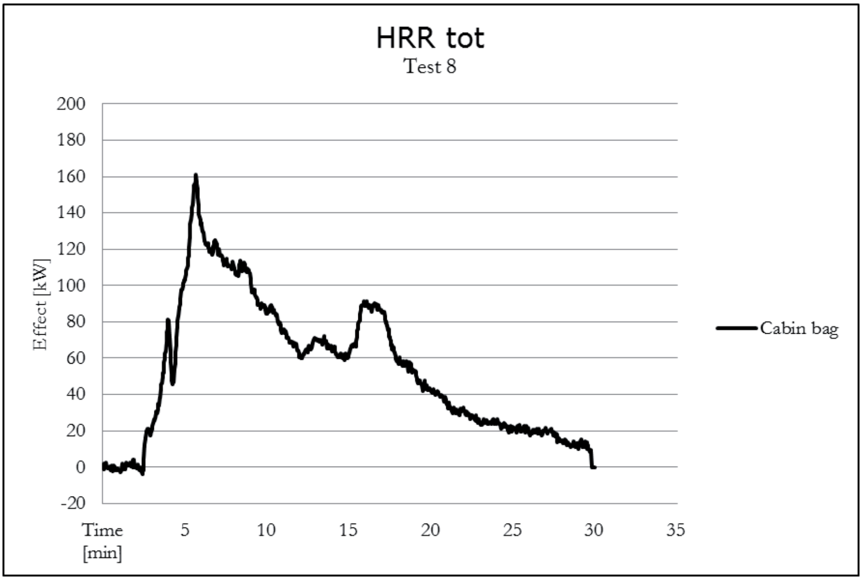


Diagram 8: Total Heat Release Rate for test 8: cabin bag

Total HRR for test 9: Shopping bag

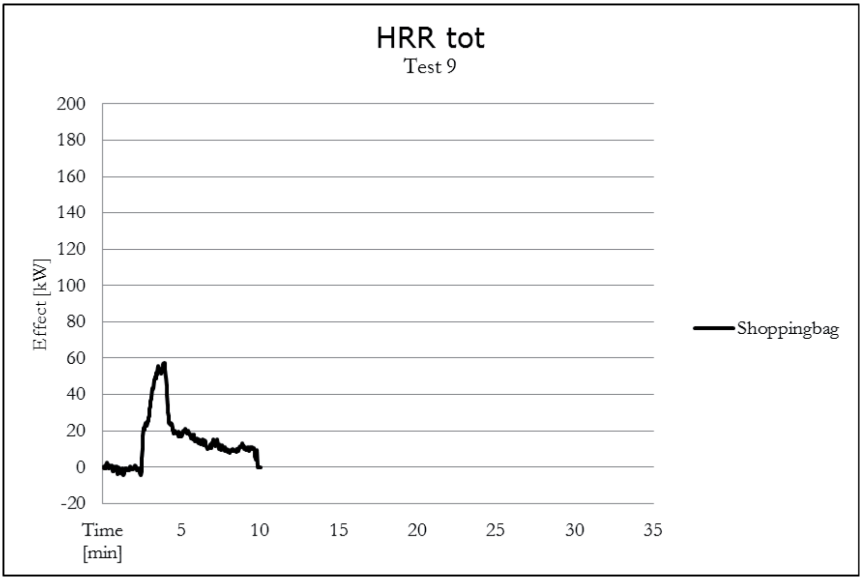


Diagram 9: Total Heat Release Rate for test 9: shopping bag

Total HRR for test 10: Rucksack

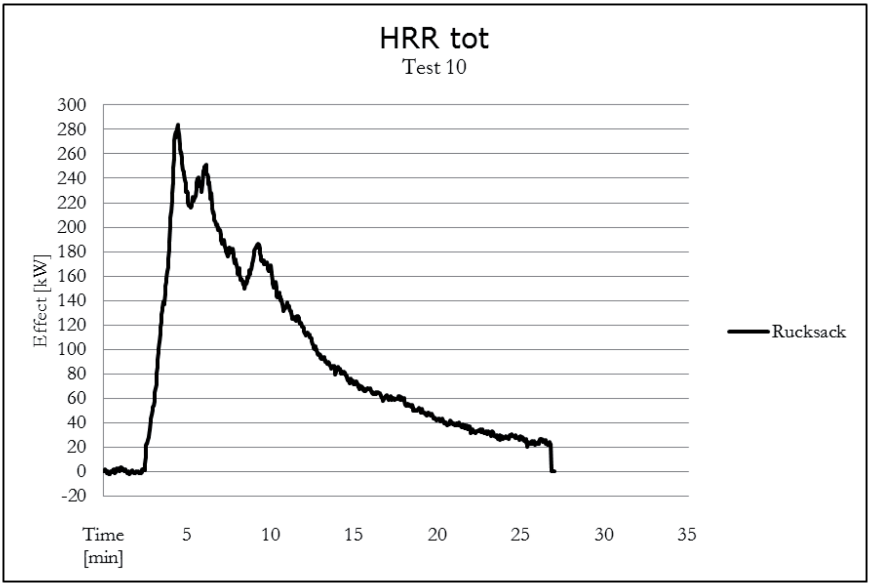


Diagram 10: Total Heat Release Rate for test 10: rucksack

Total HRR for test 11: Pram

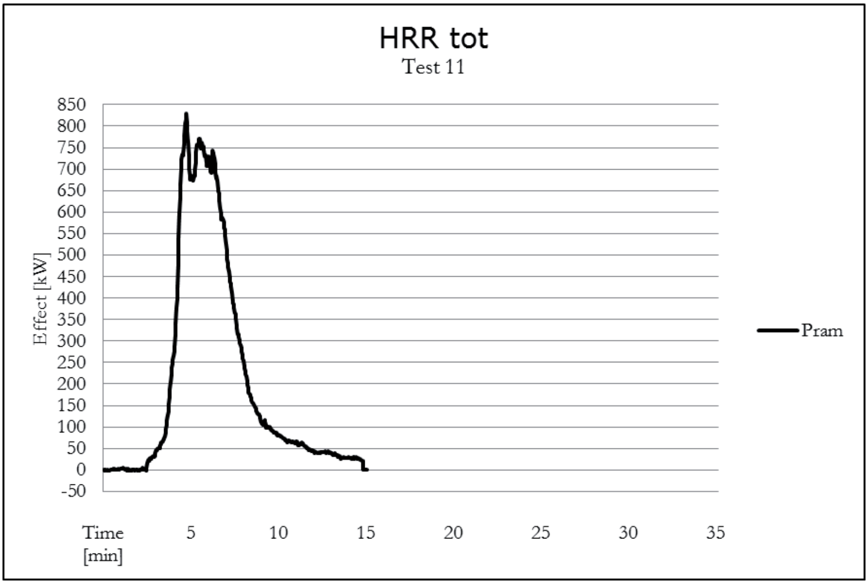


Diagram 11: Total Heat Release Rate for test 11: pram

Total HRR for test 12a: Trolley bag ("dramaten")

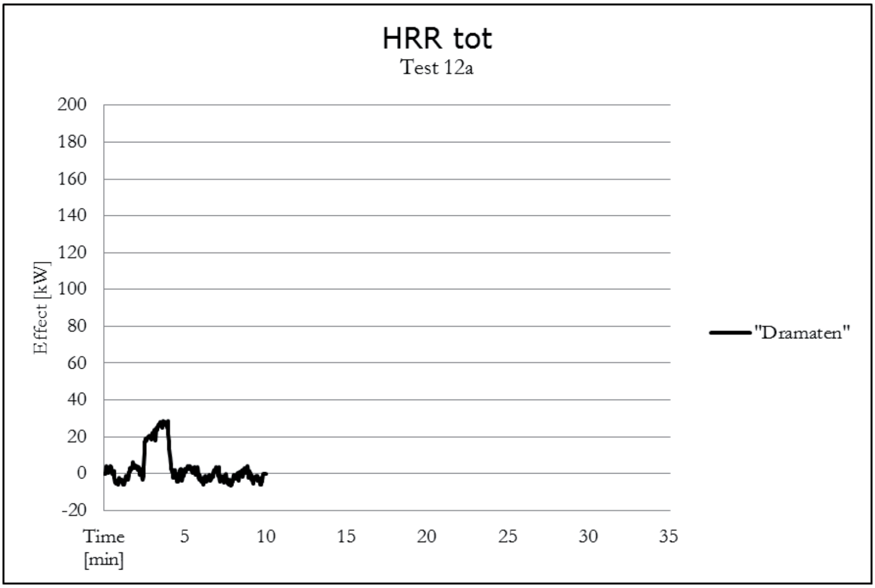


Diagram 12: Total Heat Release Rate for test 12a: trolley bag

Total HRR for test 12b: Food bags

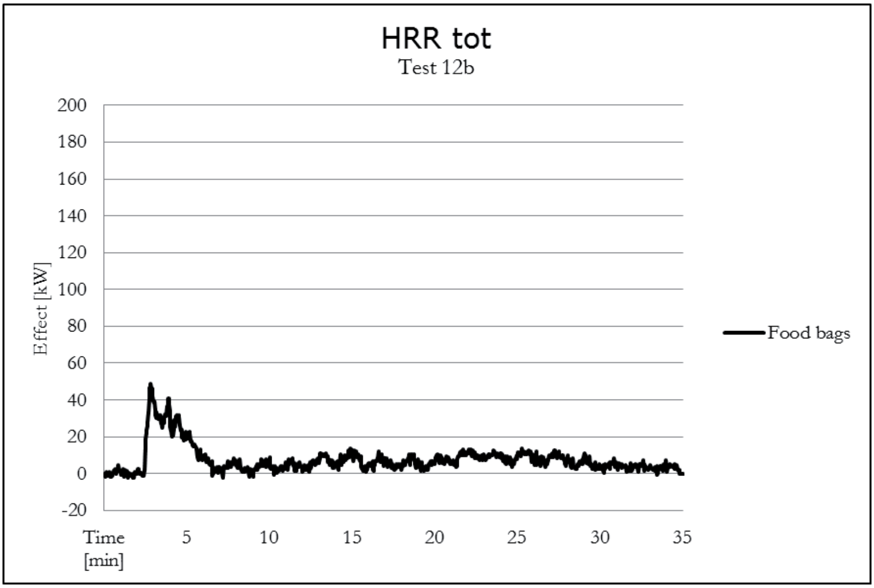


Diagram 13: Total Heat Release Rate for test 12b: food bags

Appendix 4: Energy content

Test		Material	Mass [kg]	ΔHc [kJ/kg]	Calculated E_{tot} [kJ]	Mass left [kg]	ΔHc [kJ/kg]	E_{left} [kJ]	$E_{measured}$ [kJ]	E_{tot} [kJ]
1	**Computer bag**	Electronics	2,904	26100	75794	2,629	26100	68617		
		Textile	2,664	19000	50616	0,900	19000	17100		
		Paper	0,728	17000	12376	0,500	17000	8500		
		Plastic	0,034	47000	1598	0	47000	0		
		Total	**6,330**		**140384**	**4,029**		**94217**	**45183**	**137150**
2	**Sports bag**	Textile	2,410	19000	45790	0,892	19000	16948		
		Plastic	1,258	47000	59126	0,250	47000	11750		
		Wood	0,184	18500	3404	0,040	18500	740		
		Total	**3,852**		**108320**	**1,182**		**29438**	**33113**	**60301**
3	**Tourist bag**	Textile	0,754	19000	14326	0,100	19000	1900		
		Plastic	0,518	47000	24346	0,400	47000	18800		
		Electronics	0,376	26100	9814	0,222	26100	5794		
		Paper	0,486	17000	8262	0,180	17000	3060		
		Total	**2,134**		**56748**	**0,902**		**29554**	**15307**	**42611**
4	**School bag – university**	Textile	0,312	19000	5928	0	19000	0		
		Plastic	0,226	47000	10622	0,100	47000	4700		
		Paper	4,464	17000	75888	4,448	17000	75616		
		Electronics	3,018	26100	78770	2,800	26100	73080		
		Total	**8,020**		**171208**	**7,348**		**153396**	**15549**	**166695**
5	**School bag – high school**	Textile	0,346	19000	6574	0	19000	0		
		Plastic	0,590	47000	27730	0,110	47000	5170		
		Paper	4,506	17000	76602	4,618	17000	78506		
		Electronics	0,168	26100	4385	0,200	26100	5220		
		Total	**5,610**		**115291**	**4,928**		**88896**	**7914**	**94560**

Test		Material	Mass [kg]	ΔHc [kJ/kg]	Calculated E_{tot} [kJ]	Mass left [kg]	ΔHc [kJ/kg]	E_{left} [kJ]	$E_{measured}$ [kJ]	E_{tot} [kJ]
6	**Hand-bag **/*** **	Textile	0,580	19000	11020	0,300	19000	5700		
		Plastic	0,516	47000	24252	0,200	47000	9400		
		Paper	0,718	17000	12206	0,700	17000	11900		
		Electronics	0,186	26100	4855	0,300	26100	7830		
		Metal	0,080	0	0	0,077	0	0		
		Total	**2,080**		**52333**	**1,577**		**34830**	**14661**	**47241**
7	**Suit-case *** **	Plastic	5,140	47000	241580	0,770	47000	36190		
		Textile	8,734	19000	165946	9,641	19000	183179		
		Paper	0,242	17000	4114	0,330	17000	5610		
		Metal	0,420	0	0	0,100	0	0		
		Electronics	0,192	26100	5011	0,200	26100	5220		
		Total	**14,728**		**416651**	**11,041**		**230199**	**123153**	**351102**
8	**Cabin bag*** **	Paper	0,192	17000	3264	0,300	17000	5100		
		Plastic	4,466	47000	209902	0,400	47000	18800		
		Textile	4,396	19000	83524	6,519	19000	123861		
		Total	**9,054**		**296690**	**7,219**		**147761**	**96978**	**242489**
9	**Shop-ping-bag**	Plastic	0	47000	8930	0,100	47000	4700		
		Textile	3	19000	65474	3,446	19000	65474		
		Total	**3,636**		**74404**	**3,546**		**70174**	**8536**	**76460**
10	**Ruck-sack*** **	Electronics	0,262	26100	6838	0,100	26100	2610		
		Paper	1,788	17000	30396	1,800	17000	30600		
		Plastic	1,277	47000	60019	0,600	47000	28200		
		Textile	9,152	19000	173888	8,267	19000	157073		
		Total	**12,479**		**271141**	**10,767**		**218483**	**144638**	**360871**
11	**Pram**	Metal	5,490	0	0	7,500	0	0		
		Plastic	3,836	47000	180292	0,203	47000	9541		
		Textile	5,782	19000	109858	0,500	19000	9500		
		Total	**15,108**		**290150**	**8,203**		**19041**	**179117**	**195908**
12b	**Food bags**	Food	6,172	17000	104924	7,707	17000	131019		
		Paper	0,905	17000	15385	0	17000	0		
		Plastic	0,227	47000	10669	0	47000	0		
		Metal	0,018	0	0	0	0	0		
		Glas	0,410	0	0	0	0	0		
		Total	**7,732**		**130978**	**7,707**		**131019**	**15859**	**144628**

** LPG contribution left out (25 kW, 90 s)*
*** Alcohol (796 kJ) not accounted for*
**** Butane/alcohol content not shown on container and not accounted for*

Förteckningen nedan tar upp rapporter som har publicerats inom ramen för skriftserien Studies in Sustainable Technology (SiST).

In the list below are the reports that have been published in the series of publications called Studies in Sustainable Technology (SiST).

2009:1 Kumm, Mia & Andreasson, Rolf. *Insatsövning Hallandsåstunneln 081107 - Emergency Exercise Hallandsås Tunnel 7th of November 2008.* Arbetsrapport/Work report. Projekt/Project: Tunnelbyggaren. Språk/Language: svenska, engelska/Swedish, English.

2009:2 Hansen, Rickard. *Literature survey – fire and smoke spread in underground mines.* Forskningsrapport/Research report. Projekt/Project: Gruvan. Språk/Language: engelska/English.

2009:3 Kumm, Mia. *Brandbelastning i besöksgruvor.* Arbetsrapport/Work report. Projekt/Project: Gruvan. Språk/Language: svenska/Swedish.

2009:4 Kumm, Mia. *Insatsövning i Sala Silvergruva.* Arbetsrapport/Work report. Projekt/Project: Gruvan. Språk/Language: svenska/Swedish.

2010:1 Hansen, Rickard. *Site Inventory of Operational Mines - fire and smoke spread in underground mines.* Arbetsrapport/Work report. Projekt/Project: Gruvan. Språk/Language: engelska/English.

2010:2 Hansen, Rickard. *Design Fires in Underground Mines.* Forskningsrapport/Research Report. Projekt/Project: Gruvan. Språk/Language: engelska/English.

2010:3 Kumm, Mia. *Rökfyllnadsförsök i besöksgruvor.* Arbetsrapport/Work report. Projekt/Project: Gruvan. Språk/Language: svenska/Swedish.

2010:4 Kumm, Mia. *Carried Fire Load in Mass Transport Systems.* Forskningsrapport/Research report. Projekt/Project: METRO. Språk/Language: engelska, svenska/English, Swedish.

En majoritet av rapporterna finns tillgängliga i det Digitala Vetenskapliga Arkivet (DiVA), http://mdh.diva-portal.org .

I DiVA finns avhandlingar och andra publikationer i fulltext från ett antal nordiska universitet och högskolor. Publikationerna är

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CARRIED FIRE LOADS IN MASS TRANSPORT SYSTEMS

A fire in an underground mass transport system is a great challenge for the fire and rescue services. The outcome of both the evacuation and the fire and rescue operation is dependent of the fire behavior. The fire load will influence the duration of the fire and the possible damage on the construction. It will also affect the fire and rescue services possibilities and need to extinguish the fire.

When designing new trains high fire safety requirements are raised on the carriage, the interior and the used material. The fire accidents in the Baku Metro in 1995 and in the funicular railway in the Kaprun tunnel in 2000 shows that the carried fire load also has a great impact of the fire. In this report the carried fire load in the Baku and Kaprun fires are discussed and the occurrence and location of carried fire load in the Stockholm mass transport systems is described. Based on the field study in Stockholm, typical bags and luggage have been chosen and fire test have been performed at SP Technical Research Institute of Sweden. The test includes different sizes of bags and luggage with representative contents as well as prams and shopping bags.

Mia Kumm is sharing her time at the university between tunnel research and education of engineering students in Fire Technology. She is one of the initiators of KCBU – the Swedish Centre of Excellence for Fire Safety in Underground Constructions. Mia holds a Licentiate of Engineering in Fire Technology and she is involved in the METRO project (www.metroproject.se), where full scale fire tests of metro cars in a tunnel will be performed during 2011. METRO is one of the largest on-going research projects in Europe within the field. Since 2006 Mia is honorary doctor in Fire Technology at the St Petersburg University of State Fire Services of EMERCOM, Russia.

A study from MERO

This study is published within the MERO research area (Mälardalen Energy and Resource Optimization) at Mälardalen University. The research within MERO is directed towards various aspects of a sustainable society, with particular focus on the optimization and protection of community resources and infrastructure. The research groups within the area are mainly specialized in energy efficiency, resource conservation, design of systems and processes, remediation of contaminated land and fire safety in underground facilities. A common denominator is all aspects of optimization and risk management, where modeling, simulation, validation and applied mathematics are important tools. Responsible research leader is Professor Erik Dahlquist.

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