

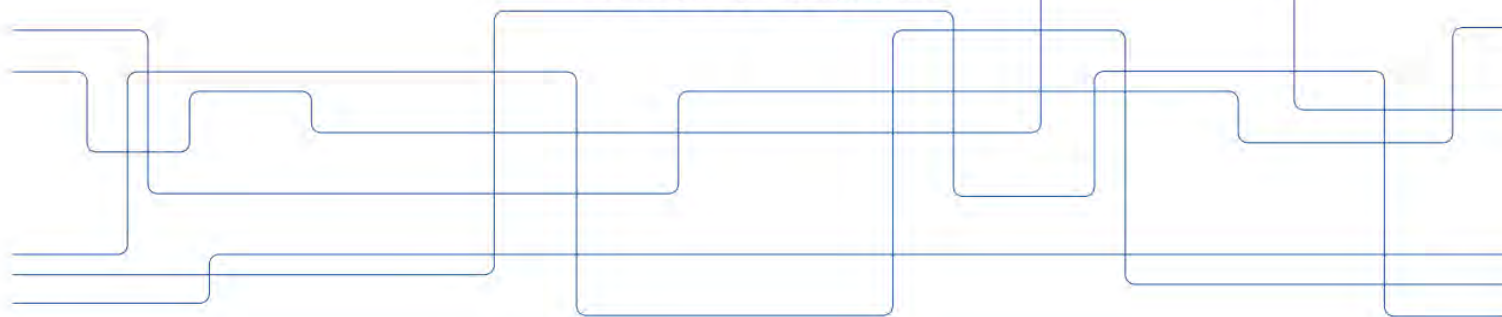


CASE STUDY ON THE ENVIRONMENTAL IMPACT AND EFFICIENCY OF TRAVEL

Evelyn Otero Sola* and Ulf Ringertz

Webbinarium "Hållbarhet & livspussel i mötespolicyn"

05/04/23, Stockholm



*otero@kth.se

- Motivation
- Study 1: Business trip to Berlin
 - Travel analysis
 - Conclusions
- Study 2: Business trip to Bordeaux
 - Travel analysis
 - Conclusions



MOTIVATION


- Internal tax introduced by KTH on air travel.
- How much extra time and cost is acceptable to reduce the environmental impact?
- Model for decision on business travel transport mode?

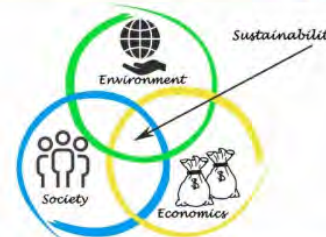


Business trips studied:

	(1) Stockholm, Sweden → Berlin, Germany	(2) Stockholm, Sweden ↔ Bordeaux, France
Transportation modes	Train, Airplane (Direct flight, Flight via Copenhagen, Turboprop aircraft), Electric car, Bus, Boat, Sailplane <i>KTH Internal rapport</i>	Train, Airplane <i>Otero, E., Ringertz, U. Case study on the environmental impact and efficiency of travel. CEAS Aeronaut J 13, 163–180 (2021). https://doi.org/10.1007/s13272-021-00547-1</i>

Based on criteria of choice from KTH regulations :
Environmental impact / Cost / Time / Safety / Work environment.

 In conflict with each other! → Complex optimization problem:
Trade-offs?? → Decisions on travel modes?





STUDY 1

BUSINESS TRIP TO BERLIN

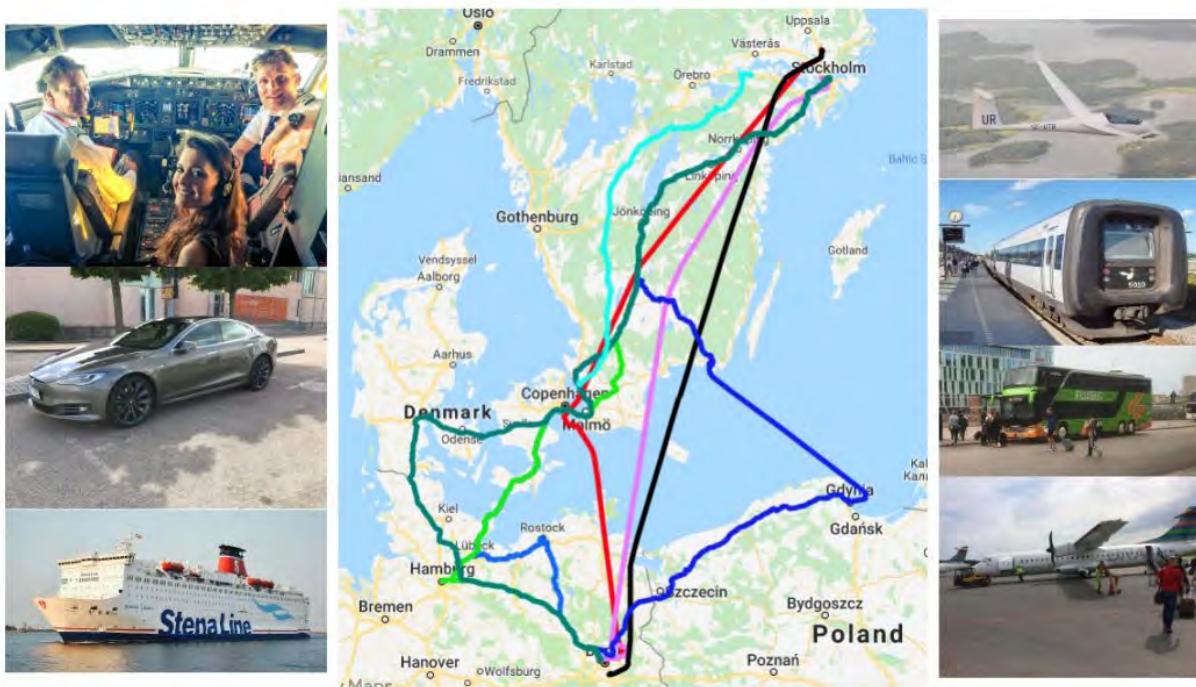
(2018)

Department of Engineering Mechanics:

Ulf Ringertz, Hans Bodén, Lars Drugge, Stefan Hallström, Natascha Jansson, Jenny Jerrelind, Zhendong Liu, Mikael Nybacka, Evelyn Otero Sola, Sebastian Stichel, Dan Zenkert

BERLIN TRIP - TRAJECTORIES

KTH → TU-Berlin (813-1450 km)



Elbil Segelflyg Buss Tåg Båt SAS Norwegian BraFlyg



BERLIN TRIP - ANALYSIS

Time

Team	Start time	Travel time	On time?
Direct flight	Sunday 17:24	05:30	yes
Bus	Sunday 13:09	18:36	45 minutes late
Flight (via Växjö)	Sunday 11:00	10:05	yes
Electric car	Saturday 10:25	20:15	yes
Train	Friday 21:00	22:00	yes (sunday rest day)
Boat	Friday 11:00	48:00	yes (rest day)
Glider	Wednesday 10:00	07:00	No, landed in Landskrona :(

Cost

Typ	SEK/person	Note
Glider	300	Initial tow (private aircraft used)
Bus	671	incl transfer
Direct flight	1000	incl shuttle transfer
Flight via Växjö	1201	incl transfer
Train	1400	excl transfer
Electric car	2261	incl car rental+hotel+tolls mm
Boat	3668	inkl taxi+train+bus etc

Safety

Number of fatalities, for 1 billion journeys, hours and passenger-kilometers

Type	Fatalities per billion		
	Journeys	Hours	pax.km
Bus	4.3	11.1	0.4
Train	20	30	0.6
Car	40	130	3.1
Walking	40	220	54.2
Boat	90	50	2.6
Flying	117	30.8	0.05
Bicycle	170	550	44.6
Motorcycle	1640	4840	108.9
Flying (1929)			625
Space Shuttle	104,000,000	442,000	2.7

Environment

	Energy (kWh)	Fuel (kg)	CO ₂ (kg)	Note
Electric car	103		9.4	Electricity
Bus	21	4	12	
Glider	10	6	17	Tow with Piper PA25
Train	115		23	Electricity + Diesel
Boat	?	12	38	uncertain data
Direct flight	60	21	65	Jet-A1
Flight via Växjö	67	25	78	Jet-A1



BERLIN TRIP - CONCLUSIONS

- Time and cost versus environmental impact (merit function?)
- Which environmental index?
- Business trips on weekends, popular?
- Travel costs small compared to working hours
- Comfort must be better for long journeys (Boat better than train?)
- Difficult to analyze certain types of transport (information missing)
- Can operators and manufacturers be trusted (Dieselgate)?
- Difficult to travel completely fossil-free (e.g. Diesel train through Denmark)
- Choose bus, or maybe train to Kastrup and then fly?



STUDY 2

BUSINESS TRIP TO BORDEAUX

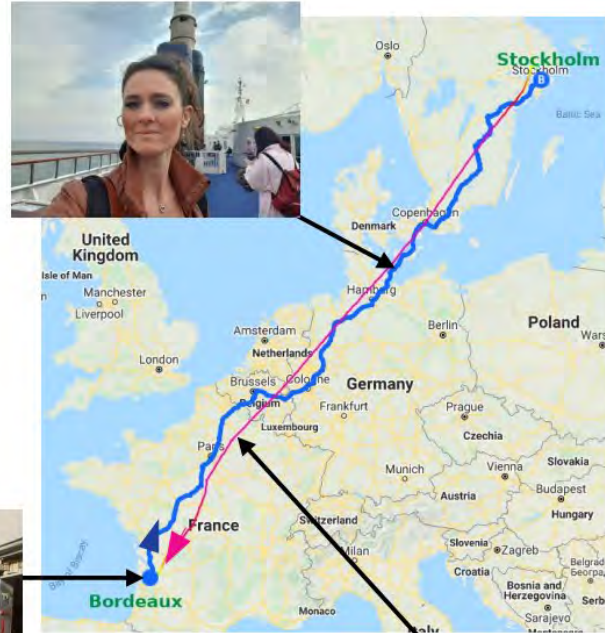
(2019)

Department of Engineering Mechanics / Aeronautics group

Evelyn Otero Sola, Ulf Ringertz

BORDEAUX TRIP - TRAJECTORIES

- **Airplane** (ARN → BOD)
 - Distance: 2063 km (ARN-BOD)
 - Direct flight: Boeing 737-800
 - Time in the air: 3 hours
- **Train** (Bordeaux → Stockholm)
 - Distance: ~2422 km
 - Number of vehicles: 11 (8 trains, 2 buses, 1 ferry)
 - Time in transport: 27 hours 38 mins





BORDEAUX TRIP - ANALYSIS:

Environmental impact

Airplane

Statistics of fuel, energy and emissions for the journey Stockholm-Bordeaux by airplane

Energy

Total fuel (ARN-BOD)	7182 kg	
Fuel/pax	57.5 kg	
Energy content of fuel used	309 GJ / (85,833 kWh)	
Energy for propulsion	86 GJ / (23,889 kWh)	
Efficiency	28%	
Total energy/pax	2472 MJ / (687 kWh)	
Energy for propulsion/pax	688 MJ / (191 kWh)	
Emissions	kg	kg/pax
CO	36.6	0.29
HC	1.4	0.011
NO _x	80.7	0.64
CO ₂	22659.2	181.3
H ₂ O	8884.1	71.1
SO _x	5.7	0.05

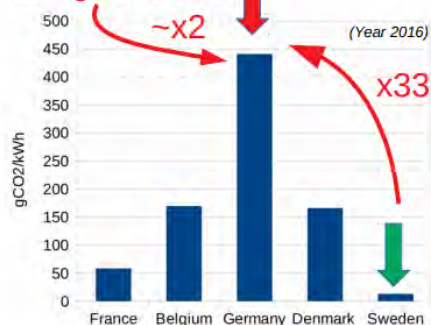


BORDEAUX TRIP - ANALYSIS: Environmental impact

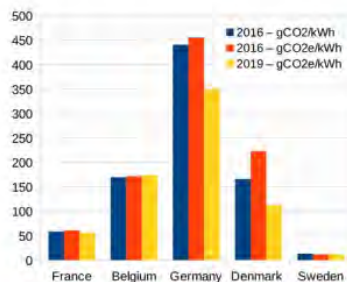
Train

Fossil fuel:

264 gCO₂/kWh!!



CO₂ emissions per 1 kWh of energy generated in a given country crossed during the journey by train.



Train Bruxelles-Köln CANCELLED!

s	Transport	Journey segment / Country(ies)	Energy type
1	TGV	Bordeaux—Haute-Picardie / France	Electricity
2	TGV	Haute-Picardie—Bruxelles M. / France-Belgium	Electricity
3	IC	Bruxelles M.—Verviers C. / Belgium	Electricity
4	Bus	Verviers C.—Aachen / Belgium-Germany	Diesel
5	Regio	Aachen—Köln Hbf / Germany	Electricity
6	ICE 4	Köln Messe-Deutz—Hamburg Hbf / Germany	Electricity
7	IC3	Hamburg Hbf—Puttgarden / Germany	Diesel
8	Bus	Rødby ferry—Copenhagen / Denmark	Diesel
9	Øresundstoget	Copenhagen—Hässleholm C. / Denmark-Sweden	Electricity
10	X 2000	Hässleholm C.—Stockholm / Sweden	Electricity

Ferry

Segment s and journey	Distance (km)	Energy (kWh)	Energy (kWh/pax)	CO ₂ (kg)	CO ₂ (kg/pax)
1	656	13120	23	767.5	1.3
2	181	3620	14.5	408.4	1.6
3	125	2077.6	6.4	352.4	1.1
4	29	111.36	1.5	30.6	0.4
5	70	1158.7	5.7	510.7	2.5
6	439	8774	35.2	3867.6	15.5
7	147	1356.9	10.5	373.1	2.9
8	160	288	5.4	79.2	1.5
9	119	1456.3	4.2	63.3	0.2
10	496	5789.5	37.4	77	0.5
Bordeaux—Stockholm (for propulsion*)	2422	37752.4	143.8	6529.8	27.5
		36523*	131.6*		

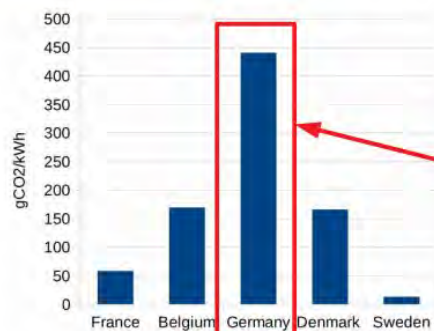
Airplane
~180 kg/
pax

Airplane: 191 kWh/pax

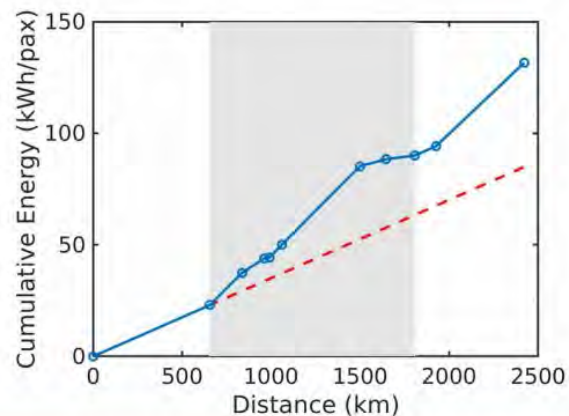
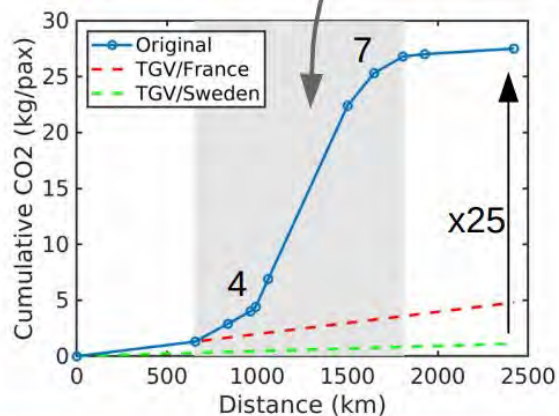
BORDEAUX TRIP - ANALYSIS: Environmental impact

Train

- Impact of the energy **generation type**



s	Transport	Journey segment / Country(ies)	Energy type
1	TGV	Bordeaux—Haute-Picardie / France	Electricity
2	TGV	Haute-Picardie—Bruxelles M. / France-Belgium	Electricity
3	IC	Bruxelles M.—Verviers C. / Belgium	Electricity
4	Bus	Verviers C.—Aachen / Belgium-Germany	Diesel
5	Regio	Aachen—Köln Hbf / Germany	Electricity
6	ICE 4	Köln Messe-Deutz—Hamburg Hbf / Germany	Electricity
7	IC3	Hamburg Hbf—Puttgarden / Germany	Diesel
8	Bus	Rødby ferry—Copenhagen / Denmark	Diesel
9	Øresundstoget	Copenhagen—Hässleholm C. / Denmark-Sweden	Electricity
10	X 2000	Hässleholm C.—Stockholm / Sweden	Electricity



BORDEAUX TRIP - ANALYSIS:

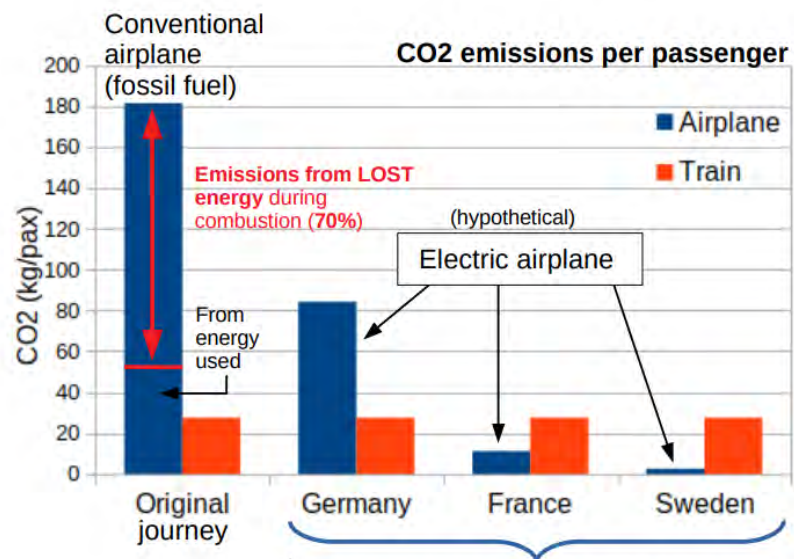
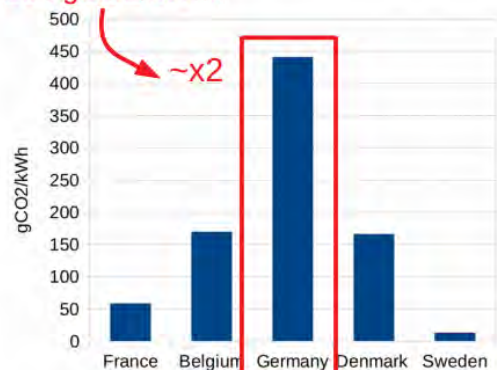
Environmental impact

Comparison

- Impact of the **energy source and its generation type**

Fossil fuel:

264 gCO₂/kWh!!



Hypothetical fully **electric airplane** with different countries for electricity generation compared to the original train journey.



BORDEAUX TRIP - ANALYSIS:

Time and cost

Comparison

Transport	Duration	Price (EUR)
TGV/ Bordeaux—Haute-Picardie	04:06	117.8
TGV/ Haute-Picardie—Bruxelles-Midi	01:34	32.7
ICE 2/ Bruxelles M.—Köln Hbf	01:53	3.2
EC 6/ Köln—Hamburg	04:07	3.2
EC/ Hamburg Hbf—Rødby ferry + bus to Copenhagen	02:45	3.2
Øresundstoget/ Copenhagen—Hässleholm C	01:25	2.4
x2000/ Hässleholm C—Stockholm	04:02	9.5
Global (Interrail Global 3 days)		229
Train travel (total)	20:00	401
+ connections time	27:38	401
+ hotel night stay	35	547.4
Direct flight	03:00	65
Bordeaux to Stockholm train station	35:40	547.4
ARN to BOD airport	07:00	65

Flight delay of 2.5 hours

BORDEAUX TRIP - ANALYSIS:

Model for optimal business travel mode choice

- **Main observation:** The whole decision analysis relies on a combined objective function mainly between environment, time, and also comfort, where a significant imbalance between environmental and social impact has been identified.

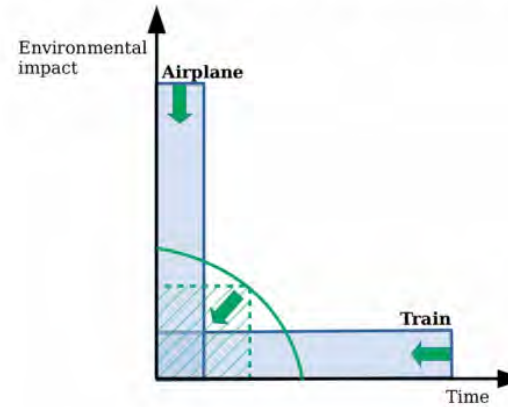
$$TM_{\text{opt}} : \min_{i \in S} TI_i(C_{\text{time},i}, C_{\text{travel},i}, S_i, E_i)$$

and

$$TI_i = \frac{1}{S_i} (E_i C_{\text{time},i} + C_{\text{travel},i})$$

TM_{opt} : An optimal travel mode

TI_i : Impact of the business journey using the travel mode i



- Travel impact for the route Stockholm–Bordeaux by airplane and train based on **objective criteria**

Travel mode	Emissions	Travel (€)	Safety	Time (€)	Travel impact
Airplane	6.5	65	1	450	2990
Train	1	547	1	2800	3347

Comfort* excluded!
(*working conditions)

BORDEAUX TRIP - ANALYSIS:

Model for optimal business travel mode choice

- Integration of personal value

$$PTI_i = \frac{1}{s_i}(PVTT_i E_i + \Delta c_i) \rightarrow PTI_i = PVTT_i E_i$$

$$\text{with } PVTT = \frac{\mu}{\lambda} - \frac{(\delta U / \delta T)}{\lambda}$$

Comfort included!

Personal value of travel time (PVTT)

Difference between the utility of the travel time or productivity if this time would be spent at the work place and the utility created during the journey.

Application examples

- Person A

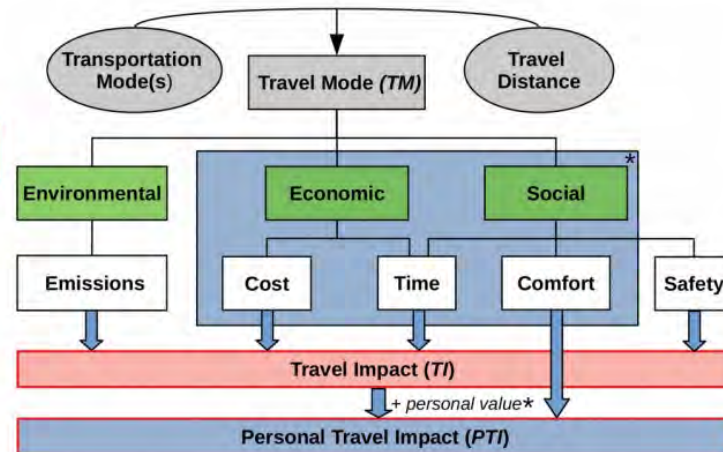
Train: unproductive \rightarrow $PVTT_{\text{train}}$ very high \rightarrow PTI_{train} highest \rightarrow **Optimal choice: Airplane**

- Person B with low budget constraint

Train: very productive \rightarrow $PVTT_{\text{train}}$ very low \rightarrow PTI_{train} lowest \rightarrow **Optimal choice: Train**

- Person B with high budget constraint

Train: very productive \rightarrow $PVTT_{\text{train}}$ very low **but** Δc_{train} very high \rightarrow PTI_{train} highest \rightarrow **Optimal choice: Airplane**

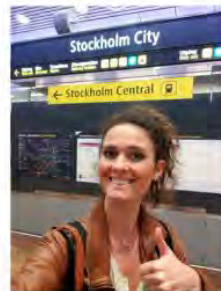


BORDEAUX TRIP - CONCLUSIONS

- **Transport mode efficiency and environmental sustainability tend to be inversely proportional to each other for long travel distances → Imbalance between environmental and social sustainability.**
 - Airplane: + (few hours journey, certainty, low cost), - (high CO2)
 - Train: - (at least a 2-day journey, high uncertainty, high cost), + (low CO2)
- **Too much uncertainty in long journeys by train** → an extra day of travel required to avoid lost of connections, stress/frustration, productivity?
 - ➡ **Need for common trains and railway infrastructures** over countries to minimize the number of connections, and higher quality conditions (night travels).
- Impact of **energy type** and its **production** (Germany vs Sweden) on the **environmental assessment of transportation modes**.
- **Time and comfort** with respect to the **environmental impact**, have been identified as the **most relevant criteria for optimal business travel mode choice**, followed by the travel cost and safety.
- Definition of a **model for optimal business travel mode choice** through an objective function based on environment, safety, comfort, time, and cost giving a value of personal travel impact (PTI).
Personal added value: comfort has been combined to the time value to account for the **personal productivity during the journey**.
- Future work: **energy consumption at the airports, train stations and hotel, external noise, materials and infrastructures more favorable for the airplane case.**



THANK YOU FOR YOUR
ATTENTION



Train journey-END

”En frisk organisation skapas inte av en slump*”

Sveriges Företagshälsor, branschorganisationen för ett hållbart arbetsliv.

Peter Munck af Rosenschöld

Sveriges Företagshälsor – om oss

- Sveriges Företagshälsor är branschorganisationen för företagshälsovård i Sverige med syfte att tillvarata och driva företagshälsovårdens intressen gemensamt.
- Föreningen är en ideell och obunden organisation, bildad 1985.
- En medlemsorganisation ledd av en styrelse – styrelseordförande är Jörgen Malmeskog.
- Sveriges Företagshälsor stöttar sina medlemmar genom att bistå med bland annat utbildning, kvalitetsutveckling och samhällskontakter.
- Agerar remissinstans för branschfrågor och bedriver opinions-bildning kring hälsa och ett hållbart arbetsliv för alla som arbetar.
- Både privata och offentliga aktörer har egen eller anlitar företagshälsovård.

feelgood

FALCK

avonova



FÖRSVARSMAKTEN

SCANIA



Region
Västernorrland

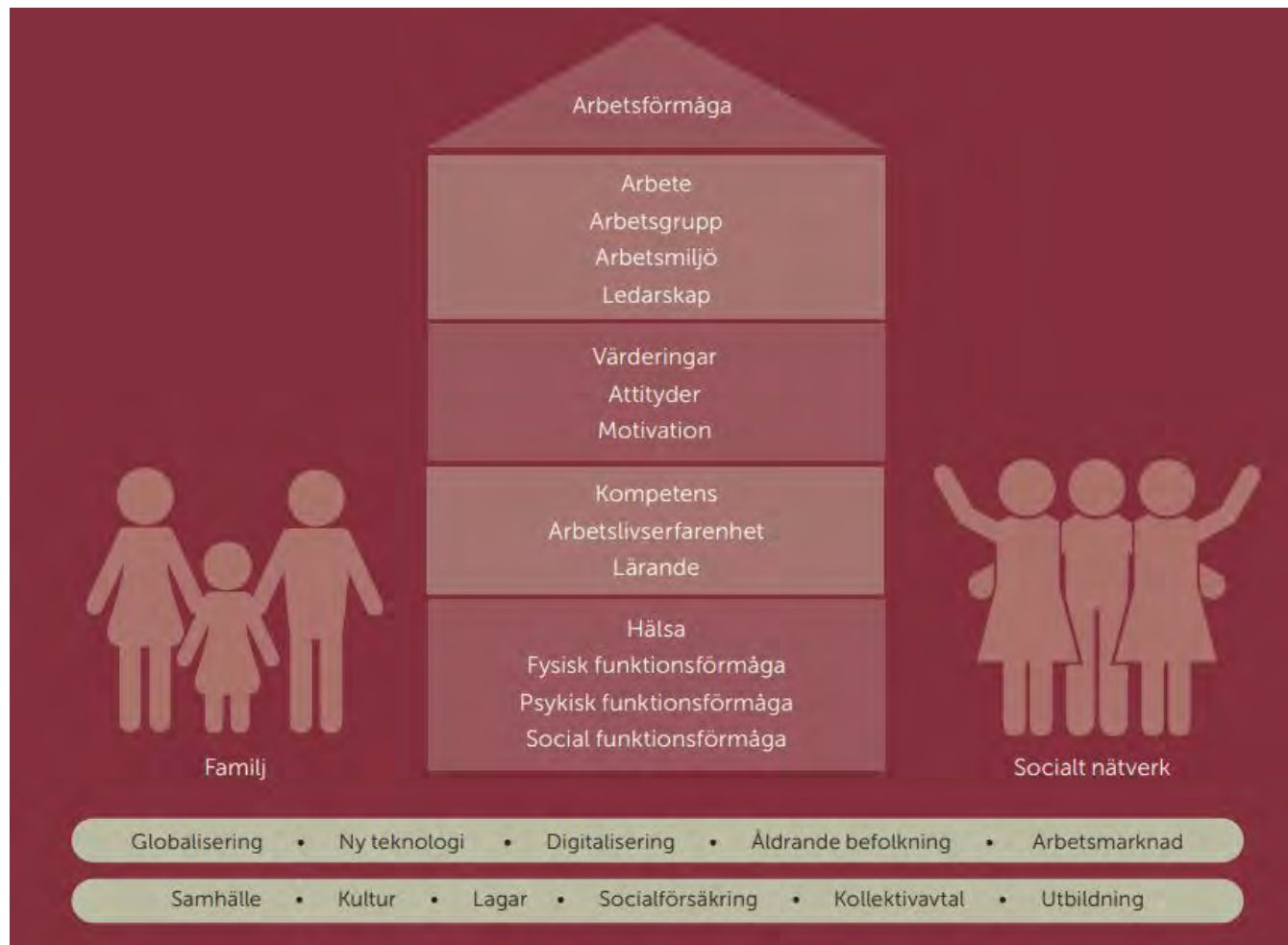
Tjugonde +
25 friskare år

Företagshälsovård

Uppdrag och riktning

- ***Förebygga och undanröja hälsorisker på arbetsplatser samt ha kompetens att identifiera och beskriva sambanden mellan arbetsmiljö, organisation, produktivitet och hälsa.***
- *Fokus är en väl fungerande arbetsförmåga och en god emotionell, kognitiv och fysisk hälsa.*
- *Utgångspunkten är individen, arbetsplatsen och organisationen.*

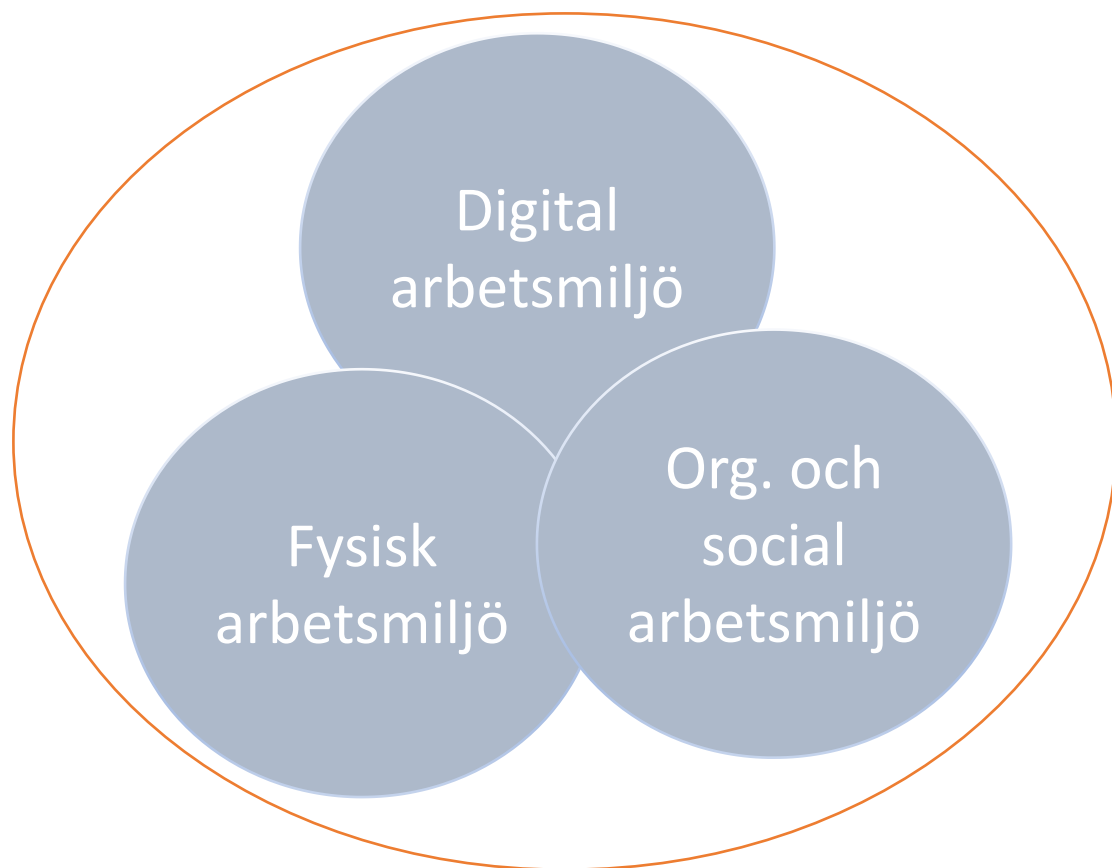
Det svenska samhället och det ekonomiska systemet bygger på vår förmåga att arbeta.



Vi har alltid vetat att det finns ett samband mellan arbete och hälsa



Men det är inte så enkelt längre



Komplexitet hanteras bäst i samverkan.



*Samtliga kategorier inom FHV har en vidareutbildning på universitet i arbetsmiljö och hälsa, eller motsvarande

För att förebygga ohälsa och främja hälsa
behövs det arbetas på flera nivåer samtidigt



ARBETSMILJÖ, HÄLSA
OCH ORGANISATION –
HUR HÄNGER DET IHOP
OCH VARFÖR?

Sveriges Företagshälsor

sveriges
företags
hälsor



Samtal om en rapport

ARBETSMILJÖ,
ORGANISATION OCH HÄLSA
– HUR HÄNGER DET IHOP
OCH VARFÖR?

Sveriges Företagshälsor

sveriges
företags
hälsor

- ”Övergripande strategiska prioriteringar är det som i slutändan skapar förutsättningarna ”på golvet”.”
- ”Det finns skäl för organisationer att både fokusera på individuella insatser och att arbeta mer övergripande med den organisatoriska strukturen och hur arbetet är organiserat.”

<https://www.foretagshalsor.se/sv/rapporter>

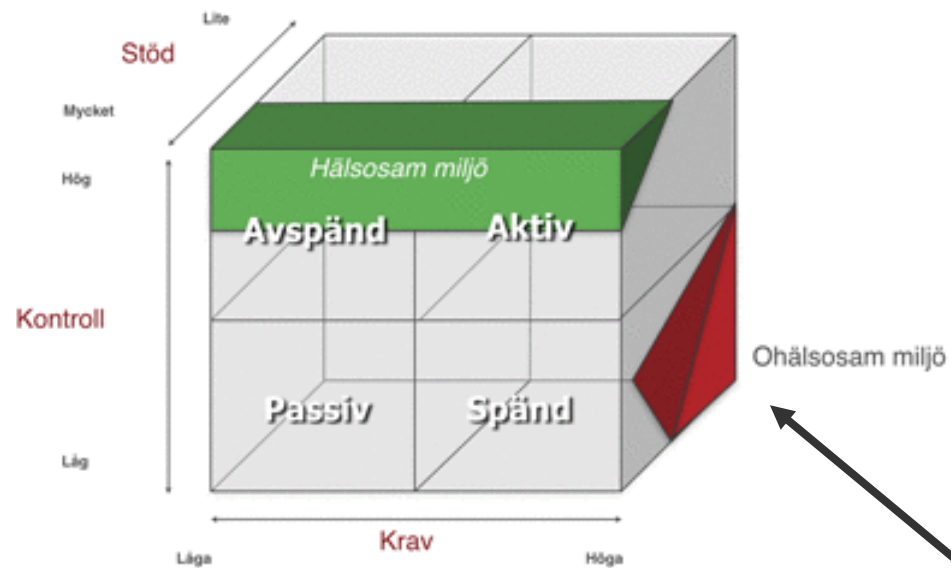
Bristande arbetsmiljö kostar

480 tusen personer var frånvarande någon gång under 2020 på grund av
bristande arbetsmiljö.

10 miljoner arbetstimmar i veckan förloras på grund av bristande arbetsmiljö

Det är skillnad mellan olika arbetsmiljöer

Kontroll – Krav – Stöd - modellen



* Karaseks och Theorells

”Tre av tio kvinnor”

En frisk organisation skapas inte av en slump
Det kräver hårt arbete



*Friskfaktorer på arbetsplatsen/Sunt
arbetsliv

För ett friskare Sverige!



- Kontaktuppgifter

- Peter.munck@foretagshalsor.se
- Tel: 070-2826862
- www.foretagshalsor.se

Beteendeskiftet är nu!

Maria Stenström



@2030sekretariatet #2030sekretariatet



maria.stenstrom@2030sekretariatet.se

Coalition of the willing and doing!



2030
SEKRETARIATET



Bilen, Bränslet, Beteendet

2030
SEKRETARIATET

Beteendeskiftet är nu!



7-punkts-checklistan för hållbart resande i jobbet

- Utgå från klimatmålen
- Måste du resa eller kan du koppla upp dig?
- Vilket är drivmedlet?
- Hur många delar på färdmedlet?
- Hur direkt kan du åka?
- Räkna hela resan
- Påverka resmålet



Välj hållbart flygbränsle



2030
SEKRETARIATET



www.2030sekretariatet.se



@2030sekretariatet #2030sekretariatet
info@2030sekretariatet.se