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Performance assessment of alternative Mediterranean transport networks by combining KPIs and Factor-Cluster Analysis

Serra Patrizia*, Fadda Paolo*, and Fancello Gianfranco *

Patrizia Serra

**DICAAR – Department of Civil, Environmental Engineering and Architecture*
University of Cagliari, Italy

❖ Focus of the study

- **Focus**: Performance assessment of maritime systems

- While the study of port performances has received a great deal of attention in the literature, only a few studies seem to have focused on the performance assessment of maritime transport chains

- This study describes a case study focused on the performance evaluation of a newly designed Mediterranean ro-ro network in order to investigate the potential improvement that would result from its entry into operation in place of the existing system

- The study provides a framework of efficiency measurement capable of describing the functioning of the analyzed transport system and comparing it with the existing transport option: first on a global level and then considering sub-groups of homogeneous services.

❖ Background literature

- Importance of performance assessment in SCM is witnessed by a large number of academic studies
- Existing studies can be classified depending on the approach they use (perspective-, process-, hierarchical- based) or on the method they apply:
  - KPIs (Lauras et al., 2011; Gunasekaran and Kobu, 2007)
  - Fuzzy techniques (El-Baz, 2011, Theeranuphattana and Tang, 2008)
  - DEA – Data Envelopment Analysis (Tavana et al., 2015; Wang and Chin, 2010)
  - Multicriteria methods (Chan et al., 2013; Galankashi et al.; 2014)
  - Balanced scorecard methods (Bhagwat and Sharma, 2007; Varma et al., 2008)
  - SCOR - Supply Chain Operations Reference models (Liepina and Kirikova, 2011; Ramaa et al., 2009)
- KPIs are among the most used models for the measurement of logistics performance, as they:
  - allow reducing the complexity of logistics systems to a small number of values
  - are useful to carry out comparative analyses between different logistics chains
  - are not predetermined and may change depending on the assumed point of view/evaluation criteria
- The use of KPIs in maritime logistics appears widespread, but limited almost exclusively to the port area (Morales Fusco et al., 2016; Owino et al., 2006; Bichou and Gray, 2004)
- A very few studies deal with performance assessment of maritime transport chains (Fancello et al., 2018)

❖ Contribution of the study

- Following a **transport-based approach**, this study provides a framework of efficiency measurement to assess and compare the operational and sustainability performances of two alternative Mediterranean transport schemes

- The basic idea is to perform a **comparative analysis** of the services that make up the two network schemes (existing and optimized) through a **set of relevant KPIs**.

- As the direct use of KPIs can yield to wrong performance assessment when analyzing miscellaneous samples in which heterogeneity can be misinterpreted as inefficiency, we apply **clustering techniques** to **avoid confusion between inefficiency and heterogeneity**.

❖ Problem setting: Case Study

- **Test area**: Mediterranean basin
- **Focus**: system of maritime connections that offer **regular ro-ro services** between the main ports of its north-western and south-eastern coastal slopes.
- **Ports involved include ro-ro ports of the following countries**:
  - France, Italy, and Spain for the north-western part;
  - Cyprus, Egypt, Lebanon, Syria, and Turkey

    for the south-eastern one.

Characterization of the two scenarios of interest:

- Existing transport scheme
- Optimized transport scheme (outcomes of the OPTIMED Project, ENPI CBC MED 2007-2013)

❖ Problem setting: Case Study

Characterization of the existing scenario

- 16 Med ro-ro liner services identified
- Construction of the network graph by identifying a single centroid node for each area:
  - 7 centroids for the EU part and 7 for the MENA part
  - 98 potential O/D connections
- This representation is useful for:
  - evaluating min O/D routes (possibility of interchange is considered when no direct connection is available)
  - determining the minimum number of stops to be made before reaching the final destination

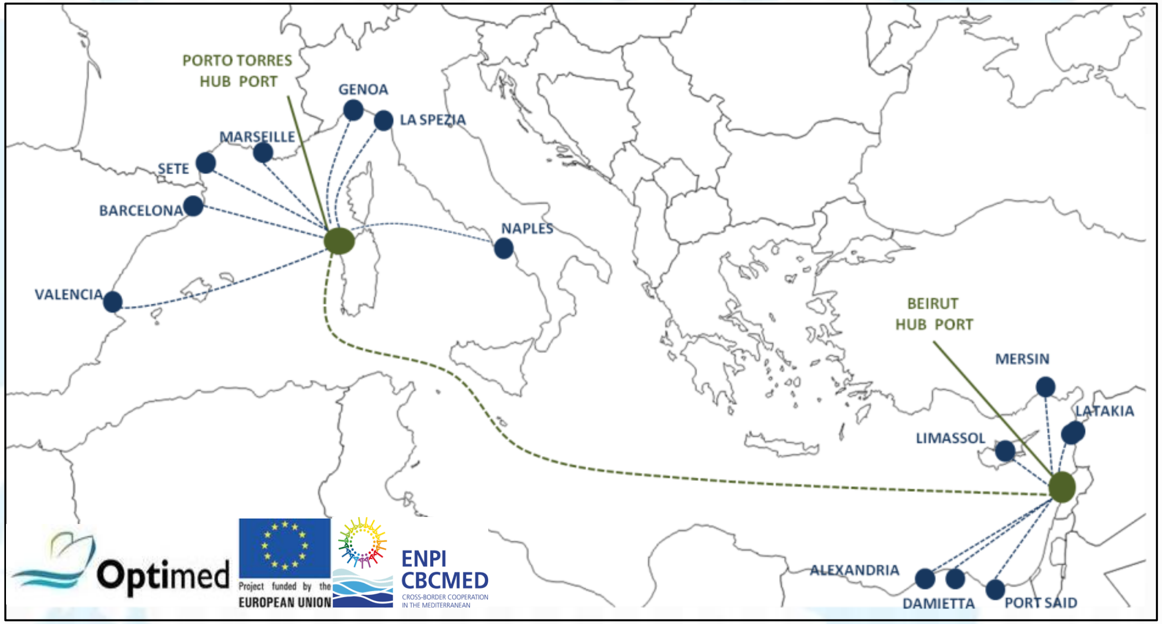
	Country	Centroid	Ports belonging to the centroid
EU area	Spain	Valencia	Valencia, Sagunto, Castellon
		Barcelona	Barcelona, Tarragona
	France	Marseille	Marseille
		Sète	Sète, Toulon
	Italy	Genoa	Genoa, Savona
		La Spezia	La Spezia, Livorno
		Naples	Naples, Salerno
MENA area	Turkey	Mersin	Mersin
	Syria	Lattakia	Lattakia, Tartous
	Lebanon	Beirut	Beirut, Tripoli
	Egypt	Alexandria	Alexandria
		Port Said	Port Said
		Damietta	Damietta
	Cyprus	Limassol	Limassol

❖ Problem setting: Case Study

Characterization of the optimized scenario

▪ Topological structure

- Two-hub-based configuration
- Each hub serves a set of O/D ports according to the hub and spoke distribution scheme
- The proposed configuration is supposed to concentrate on the two hubs and their connection the largest trading demand possible between the two shores



▪ Operating structure

Defined using a two-step optimization approach based on two interconnected Mixed Integer Linear Programming Models (MILPM):

- MILPM for optimal services frequencies and capacities
- MILPM for services timetabling

(Fadda et al., 2017)

❖ Methodology: KPIs definition

Operational KPIs:

- **WF** - Weekly Frequency of the services that make up the network (times per week);
- **WD** - Weekly Demand of the services that make up the network (lm per service);
- **SD** - Sailing Distance of the routes that make up the network (nm per travel);
- **NS** - Number of Stops from O to D of the services that make up the network (n. of stops per travel);
- **ST** - Sailing Time of the services that make up the network (h/travel);
- **PT** – Port Time of the services that make up the network (h/travel);
- **TJT** - Total Journey Time of the services that make up the network (h/travel);
- **WT** - Waiting Time (h/week). It accounts for the availability or not of the service in relation to its frequency. It is calculated as: **Waiting Time = 168 / (frequency / 2)**
- **RWTJ** - Ratio between Waiting and Total Journey Time. It is a dimensionless indicator. The lower the value, the more efficient the network.

❖ Methodology: KPIs definition

Sustainability KPIs:

- **UE** – Unitary Emission of CO_2 (kg CO_2/lm) per linear meter of transported goods along the services that make up the network. It provides a measure of the environmental efficiency of the network.

- **UR** – Utilization of the Route (lm/h). It gives an indication of the performance of the route in terms of linear meters of goods transported per each hour of travel (including waiting times).

❖ Methodology: TJT Regression

TJTR – Total Journey Time Regression:

It has been estimated for both network scenarios in the attempt to provide a tool to estimate the Total Journey Time of a given a service (**y**) based on a multiple regression model with two predictors:

- services weekly frequency ($\mathbf{x_1}$)
- number of intermediate stops along the route ($\mathbf{x_2}$)

TJTR – Existing network (70 observations)

Term	Coef	SE Coef	T-Value	P-Value	Adj SS	Adj MS	F-Value
x1	-76.70	9.98	-7.69	<0.005	632378	632378	59.11
x2	117.85	4.72	24.99	<0.005	6681607	6681607	624.53

- Goodness-of-fit statistics: **R-sq = 0.922; R-sq(adj) = 0.920; R-sq(pred) = 0.918**

TJTR – Optimized network (70 observations)

Term	Coef	SE Coef	T-Value	P-Value	Adj SS	Adj MS	F-Value
Constant	229.35	4.24	54.11	<0.005	-	-	-
	-42.78	2.88	-14.88	<0.005	6816	6815.93	221.27
	25.58	1.77	14.44	<0.005	6425	6425.29	208.59

- Goodness-of-fit statistics: **R-sq = 0.852; R-sq(adj) = 0.848; R-sq(pred) = 0.836**

❖ Methodology: KPIs Comparison

KPI	Unit of measure	Existing scenario		Optimized scenario		Desired trend	Best performing scheme	Variation (%)
		Mean	StDev	Mean	StDev			
WF	times/week	1.3	1.2	1.1	0.6	>	Existing	-15.4
WT	h/week	167.5	135.3	80.6	12.6	<	Optimized	-51.9
NS	Stops/travel	3.6	0.7	1.8	0.4	<	Optimized	-50.0
SD	nm/travel	2016.4	561.2	1883.7	126.7	<	Optimized	-6.6
ST	h/travel	106.1	29.5	93.4	7.0	<	Optimized	-12.0
PT	h/travel	65.3	8.9	55.8	5.1	<	Optimized	-14.5
TJT	h/travel	338.9	139.9	229.9	16.4	<	Optimized	-32.2
RWTJ	-	0.41	0.23	0.34	0.04	<	Optimized	-17.1
UR	lm/h	1.1	2.2	1.3	2.4	>	Optimized	+18.2
UE	kgCO_2/lm	1781	2673	429.7	155.4	<	Optimized	-75.9

Some observations

- Data are very spread out from the mean, indicating a substantial dispersion of data and a significant heterogeneity of the sample.
- Efficiency benchmarking can benefit from the combination of assessment measures with cluster analysis in order not to neglect heterogeneity and to better interpret the performances by redefining them for sub-groups of homogeneous observations.

❖ Methodology: Factor-Cluster Analysis

1. **First step**: **Factor Analysis**

$$F_i = \delta_{i0} + \delta_{i1} Y_1 + \delta_{i2} Y_2 + \ldots + \delta_{ik} Y_n + \varepsilon_i$$

Factor value — Intercept — Factor loadings — Residuals

- The number of factors to extract have been preliminary defined by performing the analysis using the principal components method of extraction, without rotation, and then using the percentage of variance to determine the amount of variance explained by the factors. The factor analysis is then repeated using the Varimax rotation to extract only the factors of interest.

2. **Second step**: **Cluster analysis**

- Hierarchical methods start with n classes, representing the n statistical units, and then use iterative processes of merging, until all units are assigned to a single cluster. The final result is a series of partitions that can be graphically represented by means of a tree-like diagram, the so-called dendrogram.

- The similarity S_{ij} between two clusters *i* and *j* is calculated as:

$$S_{ij} = \frac{100\,(1 - d_{ij})}{d_{max}}$$

d_{ij}: Distance between clusters

d_{max}: Max value in the original distance matrix

- The decision about final grouping is obtained by "cutting" the dendrogram at the appropriate level

❖ Application

1. Factor-Cluster analysis for the existing network: 72 observations (2 outliers eliminated)

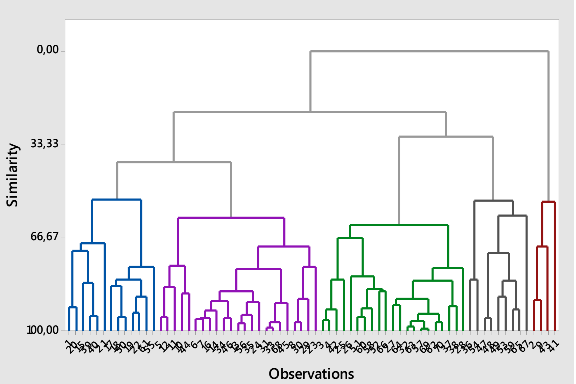
▪ **Unrotated factor loadings and communalities**

Variable		*Factor1*	*Factor2*	*Factor3*	*Factor4*	*Factor5*	*Factor6*	*Factor7*	*Communality*
WD - Weekly Demand		-0.096	-0.357	-0.830	0.180	0.377	0.010	0.000	1.000
WF - Weekly Frequency		-0.704	-0.632	-0.031	0.051	-0.197	-0.250	0.000	1.000
NS - N. of intermediate Stops		0.746	-0.650	0.116	-0.079	-0.021	0.017	0.000	1.000
SD - Sailing Distance		0.134	-0.035	-0.036	0.964	-0.216	0.064	0.000	1.000
PT - Port Time		0.746	-0.650	0.116	-0.079	-0.021	0.017	0.000	1.000
TJT - Total Journey Time		0.788	0.494	0.035	0.197	0.165	-0.259	0.000	1.000
UE – Unitary Emission of CO_2		-0.415	-0.255	0.717	0.275	0.416	0.011	0.000	1.000
Eigenvalue		2.431	1.682	1.234	1.091	0.428	0.134	0.000	7.000
% Var	92%	0.347	0.240	0.176	0.156	0.061	0.019	0.000	1.000

▪ **Rotated factor loadings and communalities using Varimax rotation**

Variable	*Factor1*	*Factor2*	*Factor3*	*Factor4*	*Communality*
WD - Weekly Demand	-0.300	-0.048	-0.851	0.204	0.858
WF - Weekly Frequency	-0.945	0.039	-0.041	0.058	0.899
NS - N. of intermediate Stops	0.091	-0.995	-0.031	0.016	0.999
SD - Sailing Distance	0.084	-0.019	-0.034	0.970	0.949
PT - Port Time	0.091	-0.995	-0.031	0.016	0.999
TJT - Total Journey Time	0.913	-0.171	0.026	0.205	0.906
UE – Unitary Emission of CO_2	-0.485	0.020	0.721	0.266	0.827
Eigenvalue	2.075	2.013	1.249	1.099	6.438
% Var	0.297	0.288	0.179	0.157	0.920

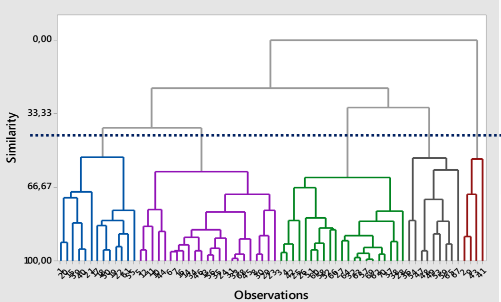
▪ **Dendrogram**



Application

1. Factor-Cluster analysis for the existing network

	Number of observations	*Within cluster Sum of squares*	*Average distance from centroid*	*Maximum distance from centroid*
Cluster1	13	28.6597	1.41039	2.15616
Cluster2	4	8.7905	1.39737	2.09318
Cluster3	21	25.4171	1.05710	1.77274
Cluster4	23	28.2685	1.03436	1.73960
Cluster5	9	19.1887	1.37573	2.21444



KPI	Unit of measure	Whole network Mean	Whole network StDev	Cluster 1 Mean	Cluster 1 StDev	Cluster 2 Mean	Cluster 2 StDev	Cluster 3 Mean	Cluster 3 StDev	Cluster 4 Mean	Cluster 4 StDev	Cluster 5 Mean	Cluster 5 StDev
WF	**times/week**	1.3	1.2	0.3	0.1	2.7	0.5	1.1	1.0	1.1	1.1	2.6	0.9
WT	**h/week**	167.5	135.3	284.3	80.7	31.5	7.0	181.8	141.9	174.4	130.2	37.6	18.8
NS	**stops/travel**	3.6	0.7	3.8	0.9	3.7	0.5	2.9	0.2	4.3	0.4	3.2	0.4
SD	**nm/travel**	2016.4	561.2	2804.6	271.6	2258.3	194.9	1613.5	272.0	1706.0	207.5	2330	563
ST	**h/travel**	106.1	29.5	147.6	14.3	118.9	10.3	84.9	14.3	89.8	10.9	122.6	29.6
PT	**h/travel**	65.3	8.9	67.2	11.1	67.0	6.0	57.4	2.6	73.1	5.4	60.7	5.3
TJT	**h/travel**	338.9	139.9	499.1	85.6	217.4	11.2	324.1	134.5	337.3	131.8	220.9	42.4
RWTJ	**-**	0.41	0.23	0.56	0.08	0.14	0.02	0.47	0.24	0.44	0.21	0.2	0.05
UR	**lm/h**	1.1	2.2	0.4	0.5	8.4	4.1	0.9	1.3	0.6	0.5	0.2	0.1
UE	**kgCO_2/lm**	1781	2673	1297	1658	704	1135	1009	1046	1005	880	6938	4302
N. of observations		**70**		**13**		**4**		**21**		**23**		**9**	

❖ Application

2. Factor-Cluster analysis for the optimized network: 72 observations (2 outliers eliminated)

▪ **Unrotated factor loadings and communalities**

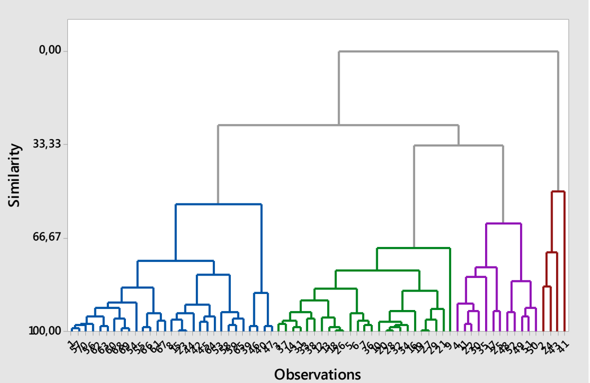
Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7	Communality
WD - Weekly Demand	-0.265	-0.770	0.200	0.473	0.272	-0.001	0.000	1.000
WF - Weekly Frequency	-0.210	-0.899	-0.224	-0.195	-0.241	-0.025	0.000	1.000
NS - N. of intermediate Stops	0.883	-0.343	0.044	-0.216	0.162	0.167	0.000	1.000
SD - Sailing Distance	0.820	-0.223	0.130	0.270	-0.434	0.007	0.000	1.000
PT - Port Time	0.873	-0.333	0.068	-0.250	0.195	-0.147	0.000	1.000
TJT - Total Journey Time	0.869	0.389	0.244	0.180	0.020	-0.032	0.000	1.000
UE – Unitary Emission of CO_2	0.497	0.092	-0.826	0.231	0.093	-0.005	0.000	1.000
Eigenvalue	3.331	1.840	0.855	0.529	0.394	0.051	0.000	7.000
% Var	0.476	0.263	0.122	0.076	0.056	0.007	0.000	1.000

86%

▪ **Rotated factor loadings and communalities using Varimax rotation**

Variable	Factor1	Factor2	Factor3	Communality
WD - Weekly Demand	0.046	-0.776	0.314	0.703
WF - Weekly Frequency	0.035	-0.945	-0.098	0.903
NS - N. of intermediate Stops	0.929	-0.067	-0.177	0.899
SD - Sailing Distance	0.854	0.041	-0.085	0.739
PT - Port Time	0.923	-0.057	-0.152	0.878
TJT - Total Journey Time	0.735	0.652	-0.029	0.966
UE – Unitary Emission of CO_2	0.230	0.108	-0.935	0.938
Eigenvalue	3.0418	1.9398	1.0442	6.0259
% Var	0.435	0.277	0.149	0.861

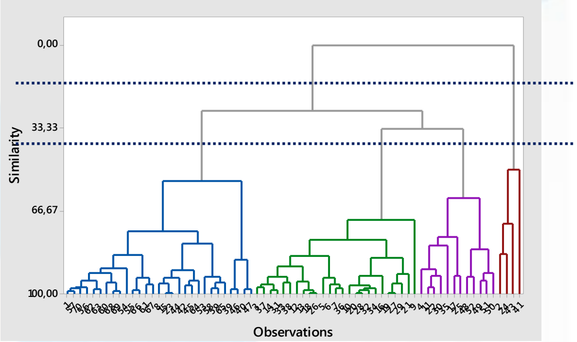
▪ **Dendrogram**



Application

2. Factor-Cluster analysis for the optimized network

	Number of observations	*Within cluster sum of squares*	*Average distance from centroid*	*Maximum distance from centroid*
Cluster1	29	21.2	0.698	2.135
Cluster2	4	7.32	1.239	1.964
Cluster3	25	6.92	0.443	1.460
Cluster4	12	9.62	0.838	1.416



KPI	Unit of measure	Whole network		Cluster 1		Cluster 2		Cluster 3		Cluster 4	
		Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
WF	times/week	1.1	0.6	1.0	0.0	2.0	0.0	1.0	0.0	1.0	0.0
WT	h/week	80.6	12.6	84.0	0.0	42.0	0.0	84.0	0.0	84.0	0.0
NS	Stops/travel	1.8	0.4	2.0	0.0	2.0	0.0	2.0	0.0	1.6	0.5
SD	nm/travel	1883.7	126.7	1923.6	97.4	1912.0	117.8	1929.0	99.6	1836.2	151.4
PT	h/travel	55.8	5.1	58.0	0.0	58.0	0.0	58.0	0.0	52.9	6.9
TJT	h/travel	229.9	16.4	237.6	5.41	194.9	6.5	237.9	5.5	227.6	14.2
RWTJ	-	0.34	0.04	0.35	0.01	0.22	0.01	0.35	0.01	0.37	0.02
UR	lm/h	1.3	2.4	0.5	0.5	6.1	5.5	1.1	1.2	1.3	1.4
UE	$kgCO_2/lm$	429.7	155.4	575.5	119.0	386.7	106.6	323.7	46.0	316.3	75.2
N. of observations		70		29		4		25		12	

❖ Results and discussion

- The clustering of the sample representing the optimized network yields to four clusters significantly more homogeneous than those characterizing the existing network

- The new network appears to be on overall better performing than the existing scenario, but a number of considerations are necessary:

    - If for a number of operational KPIs (NS, PT) the new network option always appears to be better performing than the existing scenario, on the other hand, a number of KPIs (WF, WT, RWTJT) seem to slightly worsen when the new network scheme is considered;

    - From an environmental perspective the new network appears to be clearly more efficient than the existing scheme;

    - The UR indicator appears to be the most heterogeneous variable within both samples. In fact, even if the optimized sample appears to be on average better performing than the existing one, when single clusters are analyzed it emerges that there is a numerous group of observations (cluster 1 – optimized network) for which the UR indicator assumes a lower and less desirable value than some clusters in the existing network (clusters 2, 3, and 4)

❖ Conclusions

- This study proposed a comparative analysis of the transport services that make up two alternative network options using a set of quantitative KPIs and applying a factor-cluster analysis to produce homogeneous clusters of services, while accounting for sample heterogeneity

- The applied methodology allowed to:
  - assess on a network level the performance benchmarks between the two samples, showing the better overall performance of the optimized scheme;
  - identify, within each sample, well-defined groups of services that can be benchmarked against one another, in order to put into light inefficiencies and/or proper functioning within the network.

- Outcomes support the idea that combining KPIs and factor-cluster analysis can serve as a useful decision support tool when comparing the performance of alternative transport schemes.

- Because of the different dimensions that characterize clustering, results must be analyzed carefully, since they cannot be explained by a single variable, but only by a combination of them, and might also vary depending on the perspective considered.

- As a future development, the introduction of appropriate weighting criteria of the relevant clustering variables would likely improve and sharpen the results obtained and the strength of the conclusions.

Many thanks for your attention

Patrizia Serra
pserra@unica.it

Summary Table

KPI	Unit of measure	EXISTING SCENARIO Whole network	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	OPTIMIZED SCENARIO Whole network	Cluster 1	Cluster 2	Cluster 3	Cluster 4
WF	times/week	1.3	0.3	2.7	1.1	1.1	2.6	1.1	1.0	2.0	1.0	1.0
WT	h/week	167.5	284.3	31.5	181.8	174.4	37.6	80.6	84.0	42.0	84.0	84.0
NS	Stops/travel	3.6	3.8	3.7	2.9	4.3	3.2	1.8	2.0	2.0	2.0	1.6
SD	nm/travel	2016.4	2804.6	2258.3	1613.5	1706.0	2330	1883.7	1923.6	1912.0	1929.0	1836.2
ST	h/travel	106.1	147.6	118.9	84.9	89.8	122.6	93.4	95.6	94.9	95.9	90.7
HT	h/travel	56.1	57.7	57.5	49.5	62.6	52.2	50.2	52.0	52.0	52.0	47.6
MT	h/travel	9.2	9.5	9.5	7.9	10.5	8.4	5.7	6.0	6.0	6.0	5.3
PT	h/travel	65.3	67.2	67.0	57.4	73.1	60.7	55.8	58.0	58.0	58.0	52.9
TT	h/travel	171.4	214.8	185.9	142.3	162.9	183.3	149.2	153.6	152.9	153.9	143.6
TJT	h/travel	338.9	499.1	217.4	324.1	337.3	220.9	229.9	237.6	194.9	237.9	227.6
RWTJ	-	0.41	0.56	0.14	0.47	0.44	0.2	0.34	0.35	0.22	0.35	0.37
UR	lm/h	1.1	0.4	8.4	0.9	0.6	0.2	1.3	0.5	6.1	1.1	1.3
UE	$kgCO_2/lm$	1781	1297	704	1009	1005	6938	429.7	575.5	386.7	323.7	316.3
TJTR	h/travel	326.0	419.1	231.0	260.3	415.4	181.6	230.9	237.7	195.0	237.7	212.0
N. of observations		70	13	4	21	23	9	70	29	4	25	12