DATASET OF THE REFRIGERATOR CASE

DESIGN OF CLOSED LOOP SUPPLY CHAINS: A PRODUCTION AND RETURN NETWORK FOR REFRIGERATORS

HAROLD KRIKKE, JACQUELINE BLOEMHOF-RUWAARD,
LUK N. VAN WASSENHOVE

ERIM REPORT SERIES *RESEARCH IN MANAGEMENT*	
ERIM Report Series reference number	ERS-2001-46-LIS
Publication	August 2001
Number of pages	12
Email address corresponding author	hkrikke@fbk.eur.nl
Address	Erasmus Research Institute of Management (ERIM) Rotterdam School of Management / Faculteit Bedrijfskunde Erasmus Universiteit Rotterdam P.O. Box 1738 3000 DR Rotterdam, The Netherlands Phone: +31 10 408 1182 Fax: +31 10 408 9640 Email: info@erim.eur.nl Internet: www.erim.eur.nl

ERASMUS **R**ESEARCH **I**NSTITUTE OF **M**ANAGEMENT

REPORT SERIES
RESEARCH IN MANAGEMENT

BIBLIOGRAPHIC DATA AND CLASSIFICATIONS

Abstract	This paper contains the dataset for the refrigerator case concerning the design of a production and return network for refrigerators. Section 1 emphasises the major changes to the problem structure and assumptions used by Umeda et al. (1999). Section 2 contains the parameter settings. Section 3 contains the distance matrix for all locations.	
Library of Congress Classification (LCC)	5001-6182	Business
	5201-5982	Business Science
	HF 5415.15+	Product management
Journal of Economic Literature (JEL)	M	Business Administration and Business Economics
	M 11	Production Management
	R 4	Transportation Systems
	M 11	Production Management
European Business Schools Library Group (EBSLG)	85 A	Business General
	260 K	Logistics
	240 B	Information Systems Management
	260 K	Logistics
Gemeenschappelijke Onderwerpsontsluiting (GOO)		
Classification GOO	85.00	Bedrijfskunde, Organisatiekunde: algemeen
	85.34	Logistiek management
	85.20	Bestuurlijke informatie, informatieverzorging
	85.35	Product Management
Keywords GOO	Bedrijfskunde / Bedrijfseconomie	
	Bedrijfsprocessen, logistiek, management informatiesystemen	
	Productvernieuwing, Industriele vormgeving, Logistiek, Distributiekanalen, Consumentenelektronica, Milieuzorg, Kwantitatieve methoden, Dataverzameling, Reverse Logistics, Decision Support Systems	
Free keywords	supply chain management, product design, network design, facility location, environment reverse logistics	

Dataset of the refrigerator case

Design of closed loop supply chains:
A production and return network for refrigerators

Harold Krikke[1], **Jacqueline Bloemhof-Ruwaard**[1]
Luk N. Van Wassenhove[2]

[1] Rotterdam School of Management/Fac. Bedrijfskunde, P.O. Box 1738,
3000 DR, Rotterdam, The Netherlands,
HKrikke@fbk.eur.nl, JBloemhof@fbk.eur.nl

[2]INSEAD, Boulevard de Constance, 77305 Fontainebleau, France
luk.van.wassenhove@insead.fr

Abstract

This paper contains the dataset for the refrigerator case concerning the design of a production and return network for refrigerators. Section 1 emphasises the major changes to the problem structure and assumptions used by Umeda et al. (1999). Section 2 contains the parameter settings. Section 3 contains the distance matrix for all locations.

Keywords: supply chain management, product design, network design, facility location, environment

1. Assumptions in the refrigerator case

Changes and additions compared to the original problem (Umeda et al., 1999):

- Thermal is open loop and therefore a sink and not a supply chain process
- Maintenance by the consumer is replaced by professional repair, after which the refridgerator is returned to the warehouse for sale. No modules or components are discarded after repair. There is a repair fee, that varies with the product type.
- Product designs (modular structure) are now input of the model instead of output of the model.
- Since all product designs are assumed to be equal in quality, their return quality is also assumed to be the same.
- Finished products are also send to the warehouse before sale
- The volume unit used is always kilogram
- Module and product assembly are separate processes, product and module inspection and disassembly as well as product, module and component warehousing are one process and hence can be performed at one facility.
- The purchase price of components (see table 2 in Umeda et al., 1999) is left out since this is the price consumers pay when they purchase a part for maintenance or repair (themselves).
- Facility costs are assumed to be 50% fixed and 50% variable.
- Quality parameters have been set by the authors.
- In module rebuild (p8), non reusable components (see Table 2 Umeda et al., 1999) are replaced, the others are assumed to be functioning since the module as a whole has passed the inspection (p7). In other words, there are no faulty components among the ‘reusable’ ones. Components replaced in the module rebuild process (p8) are assumed to be scrapped locally at zero cost and neutral environmental impact.
- Due to some round offs and randomising, parameter settings may in general slightly differ from (Umeda et al., 1999)
- It is assumed that energy recycling produces no by-products except energy.
- There is no time dimension in this model, hence multiple reuse is impossible. Also, aspects like MTBF are not taken into account.
- WRER and MRER are not used in this case.
- 1 Kwh = 3.6 * 10E6 Joule
- 1 yen = 1 euro cent

2. Parameter settings of the refrigerator case

The environmental optimisation criteria are e1 (energy) and e2 (waste volume).
The demand of finished product at the customer locations is V_c = 91.000 kg, divided over c=c1..c10, i.e. at each c there is a demand for a 1000 refridgerators of 91 kgs each.
The maximal volume of the external secondary market d, V_d = infinite for d=d1..d10

The supply locations s=s1..s10, are Amsterdam, Athens, Barcelona, Belgrado, Berlin, Bern, Birmingham, Bologna, Bratislawa, Nagasaki.
The customer locations c=c1..c10 are Manchester, Zaragoza, Milan, Munich, Hannover, Nuremberg, Oslo, Palermo, Paris, Prague.
The potential facility locations f=f1.. f20, are Tokyo, Brussels, Budapest, Bukarest, Cologne, Copenhagen, Dresden, Dublin, Frankfurt, Genova, Hamburg, Naples, Helsinki, Krakow, Nagano, Lisbon, Lodz, London, Lyon, Madrid.
The thermal recycling locations d=d1..d5 are Rome, Sevilla, Sofia, Stockholm, Stuttgart.
The disposal locations d=d6..d10 are Turin, Valencia, Vienna, Warswa, Marseille.
The distance matrix between the 50 locations is available on request as DISTANCE50.XLS.

The supply chain processes are p=p1 ..p9. For each process the possible facility locations are given in F(p).

P	Process description	F(p)
p1	Component manufacturing	f1, f15
p2	Warehousing	f2, f3, f11, f20
p3	Module assembly	f12, f16, f18
p4	Product assembly	f2, f3, f5, f8, f13, f14, f20
p5	Repair (maintenance)	f17, f19
p6	Disassembly	f6, f8, f14
p7	Inspection	f6, f8, f14
p8	Module rebuilt	f4, f9
p9	Material recycling	f7, f10

Section 2.1 contains the parameter settings of the components and the modules. Section 2.2 contains identity changes from material to component and from component to module for the forward chain and Section 2.3 contains the identity changes in the return part. Finally, Section 2.4 contains the cost parameters.

2.1 Components and modules

The components are a=a1..a25

Component	Description	Component	Description
a1	cabinet frame	a14	Base
a2	cabinet	a15	door 1
a3	cabinet pipe	a16	door 2
a4	duct in room	a17	door 3
a5	fan motor	a18	door 4
a6	evaporator case	a19	Gasket
a7	accumulator	a20	door plas.
a8	evaporator	a21	Spcb
a9	back grill	a22	mpcb
a10	compressor	a23	heater
a11	sideboard	a24	Tank
a12	radiator	a25	Dryer
a13	duct		

The modules are t=t1..t13

T	module weight+description	Components
t1	79.1 kg ‘reuse-1’	base, sideboard, compressor, duct, accumulator, mpcb, spcb, radiator, evacover, ductin room, pipeincabinet, glassheater, tankassembly, dryer, fanmotor, cabinet, evaporator, backgrill, cabinetframe, door 4
t2	11.9 kg ‘reuse-2’	door 1, door 2, door 3, door plas, gasket
t3	3.6 kg ‘maint-1’	spcb, fanmotor
t4	0.4 kg ‘maint-2’	dryer, pipeln cabinet
t5	0.6 kg ‘maint-3’	glassheater, evaporator
t6	2.2 kg ‘maint-4’	base, backgrill
t7	25.4 kg ‘maint-5’	cabinet frame, door 3
t8	6.8 kg ‘maint-6’	door plas, gasket
t9	2.6 kg ‘pmpp-1’	mpcb, ductin room
t10	30.7 kg ‘pmpp-2’	tank assembly, cabinet
t11	0.6 kg ‘pmpp-3’	dryer, evaporator
t12	49.7 kg ‘pmpp-4’	base, duct, radiator, cabinet frame, door 1, door 2, door 3, door 4, door plas, compressor
t13	3.7 kg ‘pmpp-5’	sideboard, accumulator, evacover, glassheater, fanmotor, backgrill

The product designs are o= o1 (reuse type), o2 (maintenance type), o3 (pmpp type)
The materials are m= m1(Fe), m2 (plastics), m3(Cu), m4 (Al)

2.2 Identity changes forward chain

w^{ma} denotes the number of kg of material m needed for the manufacturing of 1 kg of component a;

w^{ma}	material m1	material m2	material m3	material m4
a=a1	1	0	0	0
a=a2	0	1	0	0
a=a3	0	0	1	0
a=a4	0	1	0	0
a=a5	1	0	0	0
a=a6	0	1	0	0
a=a7	1	0	0	0
a=a8	0	0	0	1
a=a9	1	0	0	0
a=a10	1	0	0	0
a=a11	1	0	0	0
a=a12	1	0	0	0
a=a13	0	1	0	0
a=a14	1	0	0	0
a=a15	1	0	0	0
a=a16	1	0	0	0
a=a17	1	0	0	0
a=a18	1	0	0	0
a=a19	0	1	0	0
a=a20	0	1	0	0
a=a21	0	1	0	0
a=a22	1	0	0	0
a=a23	0	0	0	1
a=a24	0	1	0	0
a=a25	0	0	0	1

w_1^{at} denotes the number of kg of component a needed for the assembly of 1 kg of mudule t.

w_1^{at}	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13
a1	0.30	0	0	0	0	0	0.93	0	0	0	0	0.47	0
a2	0.37	0	0	0	0	0	0	0	0	0.95	0	0	0
a3	0.004	0	0	0.75	0	0	0	0	0	0	0	0	0
a4	0.01	0	0	0	0	0	0	0	0.38	0	0	0	0
a5	0.006	9	0.14	0	0	0	0	0	0	0	0	0	0.14
a6	0.01	0	0	0	0	0	0	0	0	0	0.83	0	0.24
a7	0.003	0	0	0	0	0	0	0	0	0	0	0	0.02
a8	0.006	0	0	0	0.83	0	0	0	0	0	0	0	0
a9	0.01	0	0	0	0	0.45	0	0	0	0	0	0	0.27
a10	0.10	0	0	0	0	0	0	0	0	0	0	0.16	0
a11	0.01	0	0	0	0	0	0	0	0	0	0	0	0.27
a12	0.03	0	0	0	0	0	0	0	0	0	0	0.05	0
a13	0.008	0	0	0	0	0	0	0	0	0	0	0.01	0
a14	0.015	0	0	0	0	0.54	0	0	0	0	0	0.02	0
a15	0	0.2	0	0	0	0	0	0	0	0	0	0.05	0
a16	0	0.06	0	0	0	0	0	0	0	0	0	0.01	0
a17	0	0.15	0	0	0	0	0.07	0	0	0	0	0.04	0
a18	0.02	0	0	0	0	0	0	0	0	0	0	0.04	0
a19	0	0.008	0	0	0	0	0	0.02	0	0	0	0	0
a20	0	0.56	0	0	0	0	0	0.98	0	0	0	0.13	0
a21	0.04	0	0.86	0	0	0	0	0	0	0	0	0	0
a22	0.02	0	0	0	0	0	0	0	0.62	0	0	0	0
a23	0.001	0	0	0	0.16	0	0	0	0	0	0	0	0.03
a24	0.02	0	0	0	0	0	0	0	0	0.05	0	0	0
a25	0.001	0	0	0.25	0	0	0	0	0	0	0.16	0	0

w^{at} denotes the amount of kg. of component a needed for the rebuilt of 1 kg. of module t. This table is identical to the previous one for non-reusable components, values are zero for reusable components. It is assumed that replaced components are scrapped locally at zero cost with neutral environmental impact.

w^{at}	t1	t2	t3	t4	t5	t6	T7	t8	t9	t10	t11	t12	t13
a1	0	0	0	0	0	0	0	0	0	0	0	0	0
a2	0.37	0	0	0	0	0	0	0	0	0.95	0	0	0
a3	0	0	0	0	0	0	0	0	0	0	0	0	0
a4	0.01	0	0	0	0	0	0	0	0.38	0	0	0	0
a5	0	0	0	0	0	0	0	0	0	0	0	0	0
a6	0	0	0	0	0	0	0	0	0	0	0	0	0
a7	0	0	0	0	0	0	0	0	0	0	0	0	0
a8	0	0	0	0	0	0	0	0	0	0	0	0	0
a9	0	0	0	0	0	0	0	0	0	0	0	0	0
a10	0	0	0	0	0	0	0	0	0	0	0	0	0
a11	0	0	0	0	0	0	0	0	0	0	0	0	0
a12	0	0	0	0	0	0	0	0	0	0	0	0	0
a13	0	0	0	0	0	0	0	0	0	0	0	0	0
a14	0	0	0	0	0	0	0	0	0	0	0	0	0
a15	0	0	0	0	0	0	0	0	0	0	0	0	0
a16	0	0	0	0	0	0	0	0	0	0	0	0	0
a17	0	0	0	0	0	0	0	0	0	0	0	0	0
a18	0	0	0	0	0	0	0	0	0	0	0	0	0
a19	0	0.008	0	0	0	0	0	0.02	0	0	0	0	0
a20	0	0.56	0	0	0	0	0	0.98	0	0	0	0.13	0
a21	0.04	0	0.86	0	0	0	0	0	0	0	0	0	0
a22	0	0	0	0	0	0	0	0	0	0	0	0	0
a23	0	0	0	0	0	0	0	0	0	0	0	0	0
a24	0.02	0	0	0	0	0	0	0	0	0.05	0	0	0
a25	0	0	0	0	0	0	0	0	0	0	0	0	0

w^{ao} is the amount of kg. of component a needed to assemble 1 kg. of product o. These components are non modular and directly built in

w^{ao}	o=o1	o=o2	o=o3
a1	0	0	0
a2	0	0.32	0
a3	0	0	0.003
a4	0	0.01	0
a5	0	0	0
a6	0	0.01	0
a7	0	0.003	0
a8	0	0	0
a9	0	0	0
a10	0	0.10	0
a11	0	0.01	0
a12	0	0.03	0
a13	0	0.008	0
a14	0	0	0
a15	0	0.003	0
a16	0	0.008	0
a17	0	0	0
a18	0	0.02	0
a19	0	0	0.001
a20	0	0	0
a21	0	0	0.03
a22	0	0.02	0
a23	0	0	0
a24	0	0.02	0
a25	0	0	0

w^{to} is the amount of kg. of module t needed to assemble 1 kg. of product o.

w^{to}	o=o1	o=o2	o=o3
t1	0.86	0	0
t2	0.14	0	0
t3	0	0.04	0
t4	0	0.004	0
t5	0	0.006	0
t6	0	0.02	0
t7	0	0.28	0
t8	0	0.07	0
t9	0	0	0.03
t10	0	0	0.34
t11	0	0	0.006
t12	0	0	0.55
t13	0	0	0.04

2.3 Identity changes in the return part

u_{cp} is the fraction of return flow o feasible for p5 (repair) and disassembly (p6) depending on return quality. These values are the same for all product types o=o1..o3

U_{cp}	p=p5	p=p6
C1	0.2	1
C2	0.3	1
C3	0.1	1
C4	0.5	1
C5	0.6	1
C6	0.4	1
C7	0.1	1
C8	0	1
C9	1	1
C10	0.85	1

	p=p8	p=p6	p=p2
u^t_p	0.5	1	0.2

fraction of released modules t feasible for p8 (rebuilt), p6 (further disassembly into components) and p2 (direct reuse, avaible in stock). This is due to quality reasons. These values are the same for all t.

U^a_p is the fraction of released components a feasible for p2 (direct reuse), p9 (material recycling), d1..d5 (thermal recycling) or landfill (d6). Feasibility here depends on return quality, material composition, energetic value and legislation. These values are the same for all a.

U^a_p	p=p2	p=p9	u^a_d	d=d1..d5	d=d6..d10
A1	1	1		0	0
A2	0	0		1	0
A3	1	1		0	0
a4	0	0		1	0
a5	1	1		0	0
a6	1	0		1	0
a7	1	1		0	0
a8	1	1		0	0
a9	1	1		0	0
a10	1	1		0	0
a11	1	1		0	0
a12	1	1		0	0
a13	1	1		0	0
a14	1	1		0	0
a15	1	1		0	0
a16	1	1		0	0
a17	1	1		0	0
a18	1	1		0	0
a19	0	0		0	1
a20	0	0		1	0
a21	0	0		0	1
a22	1	0		0	1
a23	1	1		0	0
a24	0	0		1	0
a25	1	1		0	0

$r^{ot} = w^{to}$
$r^{ta} = w_1^{at}$
$r^{am} = w^{ma}$
note: the reverse BOM is assumed to be the inverse assembly BOM!

2.4 Cost parameters

$T_{cost} = 0$
$T_{e1} = 0$
$T_{e2} = 0$

c^{m}_{sf} = (manufacturing price + d(s,f)*0.005) yen per kg.
For distances see distance matrix [kk.xls], s=s1..s10, f=f1..f20
manufacturing prices are:
m1: 100 yen/kg
m2: 200 yen/kg
m3: 1000 yen/kg
m4: 1500 yen/kg
in case material m cannot be supplied from s, costs are set infinite, transportation per ship incurs half the variables transportation costs

$c_{ff'}$=d(f,f')*0.005 yen per kg. f=f1..f20, f'=f1..f20, see distance matrix.
c_{fc}=d(f,d)*0.005 yen per kg. f=f1..f20 c=c1..c10
c^{a}_{fd}= disposal/thermal recycling tariff + d(f,d)*0.005 yen per kg. in case disposal is allowed else infinite

disposal tariff yen/kg	d1..d5 (thermal)	d6..d10 (disposal)
a2	100	∞
a4	100	∞
a6	100	∞
a13	100	∞
a19	∞	150
a20	100	∞
a21	∞	150
a22	∞	150
a24	100	∞

for all other a c^{a}_{fd} is infinite for all d

c^{a}_{pf}=yen/kg

c^{a}_{pf}	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13
p1	112	415	930	632	851	1077	1152	1401	433	150	683	239	438
p2	10	10	10	10	10	10	10	10	10	10	10	10	10
p7	4	3.4	30	100	200	110	500	200	100	12	100	40	180
p9	75	∞	750	∞	75	∞	75	750	75	75	75	75	∞
c^{a}_{pf}	a14	a15	a16	a17	a18	a19	a20	a21	a22	a23	a24	a25	
p1	343	367	536	214	214	2465	350	758	2033	6720	1192	2000	
p2	10	10	10	10	10	10	10	10	10	10	10	10	
p7	80	40	142	55	56	1000	149	33	67	900	71	1000	
p9	75	75	75	75	75	∞	∞	∞	∞	750	∞	750	

for other p costs are infinite. values are the same for all f, except for locations in Ireland and Eastern Europe which are 25% cheaper

c^{t}_{pf} in yen/kg

c^{t}_{pf}	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13
p2	10	10	10	10	10	10	10	10	10	10	10	10	10
p3	50	84	111	1000	667	181	16	59	154	13	667	41	324
p6	50	84	111	1000	667	181	16	59	154	13	667	41	324
p7	2.5	16.8	55.5	500	333	90.9	7.8	29.4	77	6.5	333	4	54
p8	50	84	111	1000	667	181	16	59	154	13	667	41	324

for other processes p costs are infinite. values are the same for all f, except for locations in Ireland and Eastern Europe which are 25% cheaper

c^{o}_{pf} in yen/kg

	p2	p4	p5	p6
o1	10	2	2000	2
o2	10	21	1500	21
o3	10	9	1750	9

for other processes p costs are infinite, values are the same for all f, except for locations in Ireland and Eastern Europe which are 25% cheaper

FIX_{pf} in 1000 yen

p1	p2	p3	p4	p5	p6	p7	p8	p9
34176	20000	5000	5000	1000	5000	100	500	3800

values are the same for all f

Energy costs are expressed in J/kg good flow (m,a,t,o) and calculated as follows:
$c(e1)^{m}_{sf}$ is calculated as (supply energy per material m)+(distance(s,f)*0.85J/kg/km)
use distancematrix km value times 0.85 MJ per ton, in case of ship transportation the energy times is 0.2 MJ per ton

Supply energy per material m (1 kwh = 3.6*10E6 J),

	kwh/kg	J/kg
M1	14.7	52.9 10E6
M2	0.5	1.8 10E6
M3	4.1	14.8 10E6
M4	21.1	75.9 10E6

$c(e1)_{ff'}$ is calculated as distance(f,f')*0.85J/kg/km, see distance matrix, distance in km
$c(e1)_{fc}$ is calculated as distance(f,c)*0.85 J/kg/km, see distance matrix, distance in km
$c(e1)^{a}_{fd}$ is calculated as (distance(f,d)*0.85 J/ kg/km) + (energy values of the disposal sink process d for each a)

Values of thermal recycling and disposal process in kwh/kg.

	d1..d5		d6..d10	
	Kwh/kg	J/kg	Kwh/kg	J/kg
a1	∞	∞	∞	∞
a2	-0.084	-302400	∞	∞
a3	∞	∞	∞	∞
a4	-0.084	-302400	∞	∞
a5	∞	∞	∞	∞
a6	-0.084	-302400	∞	∞
a7	∞	∞	∞	∞
a8	∞	∞	∞	∞
a9	∞	∞	∞	∞
a10	∞	∞	∞	∞
a11	∞	∞	∞	∞
a12	∞	∞	∞	∞
a13	-0.084	-302400	∞	∞
a14	∞	∞	∞	∞
a15	∞	∞	∞	∞
a16	∞	∞	∞	∞
a17	∞	∞	∞	∞
a18	∞	∞	∞	∞
a19	∞	∞	0.025	90000
a20	-0.084	-302400	∞	∞
a21	∞	∞	0.025	90000
a22	∞	∞	0.025	90000
a23	∞	∞	∞	∞
a24	-0.084	-302400	∞	∞
a25	∞	∞	∞	∞

$c(e1)^a_{pf}$ in J/kg

	a1	*a2*	*a3*	*a4*	*a5*	*a6*	*a7*	*a8*	*a9*	*a10*	*a11*	*a12*	*a13*	*a14*	*a15*	*a16*	*a17*	*a18*	*a19*	*a20*	*a21*	*a22*	*a23*	*a24*	*a25*
p1	10.8E6	18E6	11.9E6	18.7E6	10.8E6	18E6	10.8E6	11.5E6	10.8E6	10.8E6	10.8E6	11.5E6	19.1E6	11.5 E6	11.5 E6	12.6E6	11.2 E6	11.2E6	18E6	18E6	18E6	2.5E6	12.6E6	11.2E6	10.8E6
p2	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400
p7	14400	144000	108000	36000	108000	36000	180000	72000	36000	3600	36000	14400	72000	36000	14400	72000	18000	18000	360000	7200	10800	25200	360000	25200	360000
p9	52.9E6	10E40	14.8E6	10E40	52.9E6	10E40	52.9E6	36E6	52.9E6	52.9E6	52.9E6	52.9E6	10E40	52.9E6	52.9E6	52.9E6	52.9E6	52.9E6	10E40	10E40	10E40	10E40	36E6	10E40	14.8E6

for other processes p set energy use infinite. costs are the same for all f

$c(e1)^t_{pf}$ in J/kg

c^t_{pf}	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13
p2	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400
p3	72000	108000	144000	1.26E6	828000	216000	18000	72000	180000	18000	828000	108000	396000
p6	72000	108000	144000	1.26E6	828000	216000	18000	72000	180000	18000	828000	108000	396000
p7	360	28800	10800	108000	72000	18000	1440	3600	14400	1080	72000	720	10800
p8	108000	144000	180000	1.6E6	1.15E6	288000	32400	108000	252000	3240	1.18E6	144000	540000

for other processes, energy use are infinite. costs are the same for all f.

$c^o(e1)_{pf}$ in J/kg

c_{pf}	p2	p4	p5	p6
o1	14400	7200	1.8E6	7200
o2	14400	72000	1.1E6	72000
o3	14000	25200	720000	25200

for other processes, enegy use are infinite. costs are the same for all f.

		Amsterdam	Athens	Barcelona	Belgrado	Berlin	Bern	Birmingham	Bologna	Bratislawa	Nagasaki	Tokyo	Brussels	Budapest	Bukarest	Cologne	Copenhagen	Dresden	Dublin	Frankfurt	Genova	Hamburg	Naples	Helsinki	Krakow	Nagano	Lisbon	Lodz	London	Lyon	Madrid	Manchester	Zaragoza	Milan	Munich	Hannover	Nuremberg	Oslo	Palermo	Paris	Prague	Rome	Sevilla	Sofia	Stockholm	Stuttgart	Turin	Valencia	Vienna	Warsaw	Marseille
s1	Amsterdam	0	2800	1620	1800	660	850	740	1300	1210	15350	15350	210	1410	2240	260	760	810	1100	460	1280	440	1860	1830	1210	15350	2300	1140	550	920	1760	890	1560	1140	840	390	660	1370	2690	510	910	1730	2330	2190	1390	630	1150	1900	1160	1220	1280
s2	Athens	2800	0	3040	1060	2550	2420	3290	1960	1590	17680	17680	2740	1440	1120	2530	3060	2090	3700	2350	2200	2730	1090	3130	1770	17680	4270	2200	3100	2480	3620	3440	2770	2080	2000	2590	2110	3620	1390	2840	2100	1280	4020	750	3660	2230	2190	3380	1650	2300	2580
s3	Barcelona	1620	3040	0	2080	1840	920	1750	1130	1860	16650	16650	1410	2020	2650	1350	2110	1740	2110	1340	900	1790	1550	3180	2210	16650	1280	2210	1560	630	630	1900	300	1040	1370	1670	1430	2720	2370	1110	1690	1410	1010	2470	2740	1260	820	360	1760	2450	500
s4	Belgrado	1800	1060	2080	0	1310	1330	2220	900	550	15640	15640	1670	400	590	1540	1900	1040	2580	1350	1180	1600	1470	2080	730	15640	3360	1150	2030	1440	2710	2370	2260	1040	950	1540	1070	2500	2170	1780	970	1280	2970	390	2520	1180	1150	2320	650	1080	1580
s5	Berlin	660	2550	1840	1310	0	930	1360	1150	660	15650	15650	780	910	1740	570	570	190	1720	530	1130	290	1700	1460	590	15650	3000	520	1170	1230	2350	1510	2140	1010	590	290	440	1140	2450	1090	340	1490	2850	1700	1160	640	1140	2210	660	560	1520
s6	Bern	850	2420	920	1330	930	0	1160	560	920	15850	15850	640	1130	1900	580	1230	840	1520	410	490	910	1080	2300	1280	15850	2200	1310	970	310	1550	1310	1220	350	430	770	530	1840	1900	550	780	940	1930	1720	1860	340	310	1290	860	1400	580
s7	Birmingham	550	3270	1740	2230	1190	1210	0	1660	1720	16000	16000	560	1900	2680	770	1500	1350	360	960	1590	990	2220	2570	1840	16000	2420	1750	190	1110	1930	150	1700	1450	1330	1010	1170	2110	2940	640	1430	2030	2460	2610	2130	1100	1360	2080	1660	1830	1420
s8	Bologna	1300	1960	1130	900	1150	560	1660	0	790	16310	16310	1120	970	1520	1040	1660	1020	2020	880	290	1330	580	2580	1160	16310	2360	1390	1470	640	1720	1810	1410	210	560	1190	720	2220	1290	1060	930	380	2110	1280	2240	710	330	1470	740	1480	670
s9	Bratislawa	1210	1590	1860	550	660	920	1730	790	0	15950	15950	1160	190	1900	960	1220	470	2080	780	1030	950	1370	2110	390	15950	3050	530	1540	1230	2450	1870	2140	910	500	840	560	1810	2080	1290	330	2000	2840	930	1830	720	1050	2200	920	630	1410
s10	Nagasaki	15350	17680	16650	16640	15650	15850	16000	16310	15950	0	700	15480	16130	16930	15300	15440	15490	16230	15440	16230	15120	16800	16630	15950	700	17560	15860	15820	16000	17000	16050	16840	16100	15740	15130	15580	16030	17520	15780	16000	15161	17610	17020	16050	15640	16160	17020	15900	15940	16330
f1	Tokyo	15350	17680	16650	16640	15650	15850	16000	16310	15950	700	0	15480	16130	16930	15300	15440	15490	16230	15440	16230	15120	16800	16630	15950	200	17560	15860	15820	16000	17000	16050	16840	16100	15740	15130	15580	16030	17520	15780	16000	15161	17610	17020	16050	15640	16160	17020	15900	15940	16330
f2	Brussels	210	2740	1410	1670	780	640	580	1120	1160	15480	15480	0	1370	2200	220	920	790	940	410	1070	600	1680	1990	1290	15480	2090	1230	390	720	1550	730	1360	930	770	480	610	1530	2480	300	910	1520	2130	2060	1550	560	970	1700	1120	1340	1070
f3	Budapest	1410	1440	2020	400	910	1130	1950	970	190	16130	16130	1370	0	830	1160	1500	680	2310	970	1150	1200	1380	1780	370	16130	3240	630	1760	1410	2620	2100	2170	1010	690	1200	730	2100	2210	1460	570	1250	3030	790	2120	910	1060	2390	250	680	1530
f4	Bukarest	2240	1120	2650	590	1740	1900	2780	1520	1900	16930	16930	2200	830	0	1990	2350	1450	3140	1800	1770	2030	1020	2070	970	16930	3950	1280	2590	2060	3280	2930	3000	1630	1470	1980	1520	2900	2760	2290	1400	1870	3580	400	2920	1690	1920	2930	1080	1210	2150
f5	Cologne	260	2530	1350	1540	570	580	800	1040	960	15300	15300	220	1160	1990	0	750	580	1100	200	1020	430	1600	1820	1080	15300	2360	1040	610	720	1740	950	1540	880	580	290	410	1360	2430	490	700	1470	2360	1930	1380	370	890	1720	910	1130	1000
f6	Copenhagen	760	3060	2110	1900	570	1230	1500	1660	1220	15440	15440	920	1500	2350	750	0	790	1860	810	1660	320	2160	1070	1150	15440	3070	1070	1310	1460	2490	1650	2270	1520	1100	480	930	610	2960	1240	940	2000	3050	2300	630	990	1540	2470	1440	1150	1770
f7	Dresden	810	2090	1740	1040	190	840	1350	1020	470	15490	15490	790	680	1450	580	790	0	1710	470	1050	500	1570	1610	510	15490	2840	490	1160	1100	2330	1500	2010	920	470	380	310	1360	2300	1030	150	1390	2730	1410	1380	520	1020	2080	450	610	1420
f8	Dublin	1100	3700	2110	2580	1720	1520	360	2020	2080	16230	16230	940	2310	3140	1100	1860	1710	0	1350	1920	1540	2580	2930	2190	16230	2870	2110	550	1460	2220	310	2050	1770	1720	1400	1530	2470	3320	1000	1860	2360	2820	2970	2490	1460	1710	2440	2060	2280	1760
f9	Frankfurt	460	2350	1340	1350	530	410	990	880	780	15440	15440	410	970	1800	200	810	470	1350	0	860	490	1440	1880	1020	15440	2470	940	800	690	1820	1140	1600	720	400	350	220	17700	2240	570	500	1280	2310	1740	1440	210	730	1670	720	1100	1000
f10	Genova	1280	2200	900	1180	1130	490	1560	290	1030	16230	16230	1070	1150	1770	1020	1660	1050	1920	860	0	1340	700	2730	1410	16230	2180	1520	1370	470	1530	1710	1140	140	680	1140	730	2270	1470	940	1030	510	1840	1570	2290	640	180	1200	970	1650	400
f11	Hamburg	440	2730	1790	1600	290	910	1180	1330	950	15120	15120	600	1200	2030	430	320	500	1540	490	1340	0	1840	1450	880	15120	2710	790	990	1130	2170	1330	1940	1200	780	160	610	900	2640	920	630	1680	2720	1990	920	670	1210	2150	950	850	1450
f12	Naples	1860	1090	1550	1470	1700	1080	2230	580	1370	16800	16800	1680	1380	1020	1600	2160	1570	2580	1440	700	1840	0	3460	1740	16800	2370	1970	2040	1190	1990	2380	1680	770	1090	1700	1280	2750	730	1620	1490	230	2060	1850	2770	1260	890	1730	1310	1980	1090
f13	Helsinki	1830	3130	3180	2080	1460	2300	2570	2580	2110	16630	16630	1990	1780	2070	1820	1070	1610	2930	1880	2730	1450	3460	0	3780	16630	4100	1200	2380	2550	3560	2720	3360	2590	2020	1600	2330	980	4030	2310	1760	3070	4160	2460	440	2100	3040	3590	1810	1060	2840
f14	Krakow	1210	1770	2210	730	590	1280	1840	1160	390	15950	15950	1290	370	970	1080	1150	510	2190	1020	1410	880	1740	3780	0	15950	3310	240	1650	1590	2810	1990	2500	1290	860	840	820	1740	2450	1540	520	1540	3200	1110	1750	990	1430	2550	430	290	1790
f15	Nagano	15350	17680	16650	16640	15650	15850	16000	16310	15950	700	200	15480	16130	16930	15300	15440	15490	16230	15440	16230	15120	16800	16630	15950	0	17560	15860	15820	16000	17000	16050	16840	16100	15740	15130	15580	16030	17520	15780	16000	15161	17610	17020	16050	15640	16160	17020	15900	15940	16330
f16	Lisbon	2300	4270	1280	3360	3000	2200	2510	2360	3050	17560	17560	2090	3240	3950	2360	3070	2840	2870	2470	2180	2710	2370	4100	3310	17560	0	3340	2320	1830	650	2660	1020	2300	2600	2590	2520	3640	3650	1790	2910	2690	400	3750	3660	2430	2020	940	3000	3530	1780
f17	Lodz	1140	2200	2210	1150	520	1310	1750	1390	530	15860	15860	1230	630	1280	1040	1070	490	2110	940	1520	790	1970	1200	240	15860	3340	0	1560	1580	2800	1900	2500	1390	940	760	790	1640	2680	1520	510	1760	3200	1530	1660	990	1510	2550	660	130	1890
f18	London	550	3100	1560	2030	1170	970	190	1470	1540	15820	15820	390	1760	2590	610	1310	1160	550	800	1370	990	2040	2380	1650	15820	2320	1560	0	920	1670	340	1510	1220	1120	810	980	1920	2770	450	1310	1810	2270	2420	1940	910	1170	1890	1510	1730	1210
f19	Lyon	920	2480	630	1440	1230	310	1110	640	1230	16000	16000	720	1410	2060	720	1460	1100	1460	690	470	1130	1190	2550	1590	16000	1830	1580	920	0	1230	1260	920	440	730	1030	800	2040	1900	460	1080	990	1620	1820	2060	630	300	970	1160	1710	310
f20	Madrid	1760	3620	630	2710	2350	1550	1860	1720	2450	17000	17000	1550	2620	3280	1740	2490	2330	2220	1820	1530	2170	1990	3560	2810	17000	650	2800	1670	1230	0	2010	310	1670	1960	2070	2020	3100	3000	1250	2310	2040	530	3070	3120	1850	1420	340	2380	2930	1130
c1	Manchester	890	3440	1900	2370	1510	1310	150	1810	1870	16050	16050	730	2100	2930	950	1650	1500	310	1140	1710	1330	2380	2720	1990	16050	2660	1900	340	1260	2010	0	1850	1560	1460	1140	1320	2260	3110	790	1650	2150	2610	2760	2280	1250	1500	2230	1850	2070	1550
c2	Zaragoza	1560	2770	300	2260	2140	1220	1700	1410	2140	16840	16840	1360	2170	3000	1540	2270	2010	2050	1600	1140	1940	1680	3360	2500	16840	1020	2500	1510	920	310	1850	0	1260	1650	1820	1710	2860	2540	1060	1990	1630	830	2640	2870	1540	1110	320	2070	2620	780
c3	Milan	1140	2080	1040	1040	1010	350	1410	210	910	16100	16100	930	1010	1630	880	1520	920	1770	720	140	1200	770	2590	1290	16100	2300	1390	1220	440	1670	1560	1260	0	490	1010	600	2130	1550	820	870	590	1960	1430	2150	500	150	1320	820	1510	540
c4	Munich	840	2000	1370	950	590	430	1310	560	500	15740	15740	770	690	1470	580	1100	470	1720	400	680	780	1090	2020	860	15740	2600	940	1120	730	1960	1460	1650	490	0	740	170	1680	1830	830	370	920	2350	1320	1700	220	610	1710	450	1070	1060
c5	Hannover	390	2590	1670	1540	290	770	1010	1190	840	15130	15130	480	1200	1980	290	480	380	1400	350	1140	160	1700	1600	840	15130	2590	760	810	1030	2070	1140	1820	1010	740	0	470	1050	2470	770	540	1560	2650	1910	1090	520	1070	2150	970	840	1350
c6	Nuremberg	660	2110	1430	1070	440	530	1170	720	560	15580	15580	610	730	1520	410	930	310	1530	220	730	610	1280	2330	820	15580	2520	790	980	800	2020	1320	1710	600	170	470	0	1520	1990	750	290	1080	2420	1450	1530	210	720	1770	490	910	1110
c7	Oslo	1370	3620	2720	2500	1140	1840	2110	2220	1810	16030	16030	1530	2100	2900	1360	610	1360	2470	1390	2270	900	2750	980	1740	16030	3640	1640	1920	2040	3100	2260	2860	2130	1680	1050	1520	0	3570	1850	1500	2610	3610	2800	540	1560	2120	3040	1850	1700	2380
c8	Palermo	2690	1390	2370	2170	2450	1900	2960	1290	2080	17520	17520	2480	2210	2760	2430	2960	2300	3320	2240	1470	2640	730	4030	2450	17520	3650	2680	2770	1900	3000	3110	2540	1550	1830	2470	1990	3570	0	2360	2250	960	3250	2560	3590	1990	1600	2610	2030	2720	1870
c8	Paris	510	2840	1110	1780	1090	550	640	1060	1290	15780	15780	300	1460	2290	490	1240	1030	1000	570	940	920	1620	2310	1540	15780	1790	1520	450	460	1250	790	1060	820	830	770	750	1850	2360	0	1000	1400	1820	2170	1870	620	780	1440	1200	1620	770
c10	Prague	910	2100	1690	970	340	780	1500	930	330	16000	16000	910	570	1400	700	940	150	1860	500	1030	630	1490	1760	520	16000	2910	510	1310	1080	2310	1650	1990	870	370	540	290	1500	2250	1000	0	1290	2700	1360	1520	490	980	2060	320	620	1360
d1	Rome	1730	1280	1410	1280	1490	940	2000	380	2000	15161	15161	1520	1250	1870	1470	2000	1390	2360	1280	510	1680	230	3070	1540	15161	2690	1760	1810	990	2040	2150	1630	590	920	1560	1080	2610	960	1400	1290	0	2340	1670	2630	1080	690	1690	1140	1830	910
d2	Sevilla	2330	4020	1010	2970	2850	1930	2460	2110	2840	17610	17610	2130	3030	3580	2360	3050	2730	2820	2310	1840	2720	2060	4160	3200	17610	400	3200	2270	1620	530	2610	830	1960	2350	2650	2420	3610	3250	1820	2700	2340	0	3340	3630	2240	1800	650	2800	3330	1490
d3	Sofia	2190	750	2470	390	1700	1720	2610	1280	930	17020	17020	2060	790	400	1930	2300	1410	2970	1740	1570	1990	1850	2460	1110	17020	3750	1530	2420	1820	3070	2760	2640	1430	1320	1910	1450	2800	2560	2170	1360	1670	3340	0	2820	1550	1530	2700	1040	1470	1970
d4	Stockholm	1390	3660	2740	2520	1160	1860	2130	2240	1830	16050	16050	1550	2120	2920	1380	630	1380	2490	1440	2290	920	2770	440	1750	16050	3660	1660	1940	2060	3120	2280	2870	2150	1700	1090	1530	540	3590	1870	1520	2630	3630	2820	0	1580	2140	3060	1870	1720	2400
d5	Stuttgart	630	2230	1260	1180	640	340	1100	710	720	15640	15640	560	910	1690	370	990	520	1460	210	640	670	1260	2100	990	15640	2430	990	910	630	1850	1250	1540	500	220	520	210	1560	1990	620	490	1080	2240	1550	1580	0	610	1600	680	1110	940
d6	Turin	1150	2190	820	1150	1140	310	1360	330	1050	16160	16160	970	1060	1920	890	1540	1020	1710	730	180	1210	890	3040	1430	16160	2020	1510	1170	300	1420	1500	1110	150	610	1070	720	2120	1600	780	980	690	1800	1530	2140	610	0	1160	990	1620	370
d7	Valencia	1900	3380	360	2320	2210	1290	2080	1470	2200	17020	17020	1700	2390	2930	1720	2470	2080	2440	1670	1200	2150	1730	3590	2550	17020	940	2550	1890	970	340	2230	320	1320	1710	2150	1770	3040	2610	1440	2060	1690	650	2700	3060	1600	1160	0	2160	2680	850
d8	Vienna	1160	1650	1760	650	660	860	1700	740	920	15900	15900	1120	250	1080	910	1440	450	2060	720	970	950	1310	1810	430	15900	3000	660	1510	1160	2380	1850	2070	820	450	970	490	1850	2030	1200	320	1140	2800	1040	1870	680	990	2160	0	690	1370
d9	Warsaw	1220	2300	2450	1080	560	1400	1920	1480	630	15940	15940	1340	680	1210	1130	1150	610	2280	1100	1650	850	1980	1060	290	15940	3530	130	1730	1710	2930	2070	2620	1510	1070	840	910	1700	2720	1620	620	1830	3330	1470	1720	1110	1620	2680	690	0	1980
d10	Marseille	1280	2580	500	1580	1520	580	1400	670	1410	16330	16330	1070	1530	2150	1000	1770	1420	1760	1000	400	1450	1090	2840	1790	16330	1780	1890	1210	310	1130	1550	780	540	1060	1350	1110	2380	1870	770	1360	910	1490	1970	2400	940	370	850	1370	1980	0

Publications in the Report Series Research[*] in Management

ERIM Research Program: “Business Processes, Logistics and Information Systems”

2001

Bankruptcy Prediction with Rough Sets
Jan C. Bioch & Viara Popova
ERS-2001-11-LIS

Neural Networks for Target Selection in Direct Marketing
Rob Potharst, Uzay Kaymak & Wim Pijls
ERS-2001-14-LIS

An Inventory Model with Dependent Product Demands and Returns
Gudrun P. Kiesmüller & Erwin van der Laan
ERS-2001-16-LIS

Weighted Constraints in Fuzzy Optimization
U. Kaymak & J.M. Sousa
ERS-2001-19-LIS

Minimum Vehicle Fleet Size at a Container Terminal
Iris F.A. Vis, René de Koster & Martin W.P. Savelsbergh
ERS-2001-24-LIS

The algorithmic complexity of modular decompostion
Jan C. Bioch
ERS-2001-30-LIS

A Dynamic Approach to Vehicle Scheduling
Dennis Huisman, Richard Freling & Albert Wagelmans
ERS-2001- 35-LIS

Effective Algorithms for Integrated Scheduling of Handling Equipment at Automated Container Terminals
Patrick J.M. Meersmans & Albert Wagelmans
ERS-2001-36-LIS

Rostering at a Dutch Security Firm
Richard Freling, Nanda Piersma, Albert P.M. Wagelmans & Arjen van de Wetering
ERS-2001-37-LIS

Probabilistic and Statistical Fuzzy Set Foundations of Competitive Exception Learning
J. van den Berg, W.M. van den Bergh, U. Kaymak
ERS-2001-40-LIS

Design of closed loop supply chains: a production and return network for refrigerators
Harold Krikke, Jacqueline Bloemhof-Ruwaard & Luk N. Van Wassenhove
ERS-2001-45-LIS

---

[*] A complete overview of the ERIM Report Series Research in Management:
http://www.ers.erim.eur.nl

ERIM Research Programs:

LIS	Business Processes, Logistics and Information Systems
ORG	Organizing for Performance
MKT	Marketing
F&A	Finance and Accounting
STR	Strategy and Entrepreneurship

Dataset of the refrigerator case. Design of closed loop supply chains: a production and return network for refrigerators
Harold Krikke, Jacqueline Bloemhof-Ruwaard & Luk N. Van Wassenhove
ERS-2001-46-LIS

2000

A Greedy Heuristic for a Three-Level Multi-Period Single-Sourcing Problem
H. Edwin Romeijn & Dolores Romero Morales
ERS-2000-04-LIS

Integer Constraints for Train Series Connections
Rob A. Zuidwijk & Leo G. Kroon
ERS-2000-05-LIS

Competitive Exception Learning Using Fuzzy Frequency Distribution
W-M. van den Bergh & J. van den Berg
ERS-2000-06-LIS

Models and Algorithms for Integration of Vehicle and Crew Scheduling
Richard Freling, Dennis Huisman & Albert P.M. Wagelmans
ERS-2000-14-LIS

Managing Knowledge in a Distributed Decision Making Context: The Way Forward for Decision Support Systems
Sajda Qureshi & Vlatka Hlupic
ERS-2000-16-LIS

Adaptiveness in Virtual Teams: Organisational Challenges and Research Direction
Sajda Qureshi & Doug Vogel
ERS-2000-20-LIS

Assessment of Sustainable Development: a Novel Approach using Fuzzy Set Theory
A.M.G. Cornelissen, J. van den Berg, W.J. Koops, M. Grossman & H.M.J. Udo
ERS-2000-23-LIS

Applying an Integrated Approach to Vehicle and Crew Scheduling in Practice
Richard Freling, Dennis Huisman & Albert P.M. Wagelmans
ERS-2000-31-LIS

An NPV and AC analysis of a stochastic inventory system with joint manufacturing and remanufacturing
Erwin van der Laan
ERS-2000-38-LIS

Generalizing Refinement Operators to Learn Prenex Conjunctive Normal Forms
Shan-Hwei Nienhuys-Cheng, Wim Van Laer, Jan Ramon & Luc De Raedt
ERS-2000-39-LIS

Classification and Target Group Selection bases upon Frequent Patterns
Wim Pijls & Rob Potharst
ERS-2000-40-LIS

Average Costs versus Net Present Value: a Comparison for Multi-Source Inventory Models
Erwin van der Laan & Ruud Teunter
ERS-2000-47-LIS

Fuzzy Modeling of Client Preference in Data-Rich Marketing Environments
Magne Setnes & Uzay Kaymak
ERS-2000-49-LIS

Extended Fuzzy Clustering Algorithms
Uzay Kaymak & Magne Setnes
ERS-2000-51-LIS

Mining frequent itemsets in memory-resident databases
Wim Pijls & Jan C. Bioch
ERS-2000-53-LIS

Crew Scheduling for Netherlands Railways. "Destination: Curstomer"
Leo Kroon & Matteo Fischetti
ERS-2000-56-LIS