E-companion to "Stochastic Programming for Dynamic Temperature Control in Refrigerated Trucking"

EC.1. Cooling Unit

As mentioned in Larsen et al. (2007), parameters of equation (12) of the main paper depend directly on the refrigerant used (via a and b coefficients), the properties of the evaporator (via γ), and the external temperature (via P_{ci}):

$$\theta_{i1} = -\frac{\gamma a_{21}}{a_1 P_{ci} + b_1}, \tag{EC.1}$$

$$\theta_{i2} = -\frac{\gamma (a_{22} P_{ci} + b_2)}{a_1 P_{ci} + b_1}, \tag{EC.2}$$

$$\theta_{i3} = \frac{\gamma a_{21}}{a_1 P_{ci} + b_1}, \tag{EC.3}$$

$$\theta_{i4} = \frac{\gamma (a_{22} P_{ci} + b_2)}{a_1 P_{ci} + b_1}. \tag{EC.4}$$

Where P_{ci} is the fluid pressure at the condenser which depends on the temperature of the external environment T_i^{ext} and therefore varies with time.

The following coefficient values are used in the approximations of the refrigerant properties for R134a (Larsen et al. 2007)

$$a_1 = -6.7014 \cdot 10^3,\ b_1 = 2.1729 \cdot 10^5,\ a_{21} = -9.0496 \cdot 10^2,\ a_{22} = 3.367 \cdot 10^3,\ b_2 = -3.152 \cdot 10^3. \tag{EC.5}$$

EC.2. Case Study Parameters

Parameter	Value	Unit	Description	Source
c'	1005.6	J/kgK	Internal air specific heat	CuriosityFluids
v	2.6	kg/s	Air infiltration rate	Zhang et al. (2018)
A	153.9	m^2	Trailer surface	Mandersloot
A'	146.9	m^2	Walls surface	Mandersloot
A_p	1.9	m^2	Product surface	Europallet
U	0.4	W/m^2K	Wall's transmittance	Mandersloot
γ	300	W/m^2K	Evaporator's transmittance	The Engineering ToolBox
$\overline{W}$	8-10-12	kW	Unit capacity	Mandersloot
$\underline{T_p}$, $\overline{T_p}$	274-277	K	Temperature range	Aung and Chang (2014)
$\overline{h_p}$	2-4-6	W/m^2K	Product heat transfer coefficient	Kondjoyan (2006)
σ	$9.504 \cdot 10^3$	kJ/L	Fuel conversion factor	Stellingwerf et al. (2018)
C_p	$7.8 \cdot 10^2$	kJ/K	Product heat capacity	The Engineering ToolBox
C	120.513	kJ/K	Internal air heat capacity	Mandersloot

Table EC.1 Summary of the parameters employed in our model.

EC.3. Notation

Category	Symbol	Type / Unit	Description
Sets and Indices	$\mathcal{T}$	Set	Time points in the fine discretization
	$\mathcal{L}$	Set	Time points during door opening (cargo handling)
	$\mathcal{D}$	Set	Time points during driving
	S	Index	Number of decision stages (customer stops)
	$s \in [S]$	Index	Stage index
	$\mathcal{T}_s$	Set	Time points belonging to stage s
	$\mathcal{L}_s$	Set	Time points in stage s during cargo handling
	$\mathcal{D}_s$	Set	Time points in stage s during driving
	$i_0(s)$	Index	First time point in the driving phase of stage s
	$\mathcal{P}_i$	Set	Products inside the truck at time i
	p	Index	Product index
Deterministic Parameters	Δ_i	s	Time elapsed between i and $i+1$
	Δ_D	s	Fixed time interval during driving
	T_i^{ext}	K	External temperature at time i
	$\overline{T}_p, \underline{T}_p$	K	Upper and lower temperature bounds for product p
	C	J/K	Heat capacity of air inside the trailer
	C_p	J/K	Heat capacity of product p
	α_i	W/K	Heat transfer coefficient between air and external environment
	β_{pi}	W/K	Heat transfer coefficient between product p and air
	γ_i	W/K	Heat transfer coefficient between cooling fluid and air
	W	W	Maximum capacity of the refrigeration unit
	Γ	K	Lower bound on cooling fluid temperature
	$\varphi_{0,i,k}, \varphi_{1,i,k}, \varphi_{2,i,k}$	–	Coefficients for piecewise linear power consumption approximation
	σ	kJ/L	Fuel conversion factor
	B	L	Fuel budget (in model variant with constraint (19))
Stochastic Parameters	O_s	s	Door opening duration at stop s (random)
	$T_{p,i_0(s)}$	K	Initial temperature of product p loaded at stop s (random)
	ξ_s	–	Random data vector at stage s: $\xi_s = ((T_{p,i_0(s)})_{p \in \mathcal{P}_{i_0(s)} \setminus \mathcal{P}_{i_0(s-1)}}, O_s)$
Decision Variables	T_i^{air}	K	Air temperature at time i
	T_i^{cu}	K	Cooling fluid (refrigerant) temperature at time i
	T_{pi}	K	Temperature of product p at time i
	W_i	W	Electrical power consumed by refrigeration unit at time i
	ν_{pi}	K	Temperature violation of product p at time i (defined in (16))
	μ	L	Slack variable for fuel budget constraint (in model variant (19))

Table EC.2 Notation summary: sets, parameters, and decision variables

EC.4. Handling Schedule

References

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Stop	R1		R2		R3		R4		R5	
	In	Out	In	Out	In	Out	In	Out	In	Out
Depot	25	0	20	0	18	0	15	0	10	0
1	2	8	2	1	2	1	2	1	2	2
2	2	0	2	1	2	2	2	4	2	0
3	2	3	2	4	2	0	2	1	2	1
4	2	1	2	3	2	1	2	3	2	1
5	2	8	2	1	2	2	2	3	2	2
6	0	15	0	20	2	3	0	13	2	2
7	-	-	-	-	2	7	-	-	2	2
8	-	-	-	-	2	2	-	-	2	3
9	-	-	-	-	2	3	-	-	2	3
10	-	-	-	-	2	2	-	-	2	2
11	-	-	-	-	0	15	-	-	2	2
12	-	-	-	-	-	-	-	-	2	2
13	-	-	-	-	-	-	-	-	2	2
14	-	-	-	-	-	-	-	-	2	3
15	-	-	-	-	-	-	-	-	0	11

Table EC.3 Pallets loaded and unloaded at each stop for all routes.

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