VRP with Time Windows Considering Driving and Working Hour Regulations

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Where innovation starts

The play of today

- Act I
  - The EU Regulations
- Act II
  - The Challenges
- Act III
  - Mathematical Formulation
- Act IV
  - Solution Methodology
- Act V
  - Computational Results
- Epilogue

Act I: The EU Regulations

Regulation (EC) No. 561/2006 of the E.U. for "driving" regulations

&

Directive 2002/15/EC of the E.U. for "working" regulations

- Calendar Week
- Breaks (Short and Long)
- Rests (Short and Long)
- Regular Daily Rests
- Splitting Rests
- Reduced Daily Rests
- Weekly Rests
- Interval Driving / Working Time
- Daily Driving / Working Time
- Weekly Driving / Working Time

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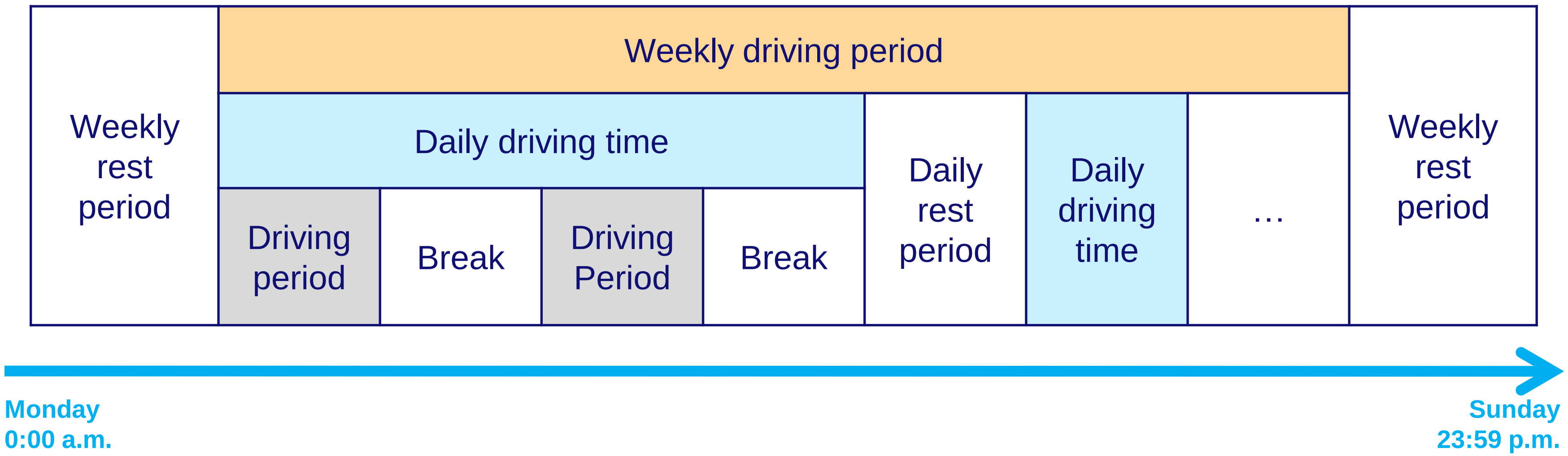
Act I: The EU Regulations

The Overall Structure



Effective since April 2007

*** Source: Kok *et al.* (2010)**

Act I: The EU Regulations

	US	CAN	EU (basic)	EU (all)	AUS (std.)	AUS (BFM)
Duration of a long rest period	10	8	11	9	7	7
Driving time between two long rest periods	11	13	9	10	12	14
On-duty time between two long rest periods	14^{+}	14^{+}	12.25	14.25	12	14
Time elapsed between two long rest periods	14^{+}	16^{+}	13	15	17	17
Driving time within six days	60	70	56	56	72	72
On-duty time within six days	60^{+}	70^{+}	60	60	72	72

Goel and Vidal, 2013

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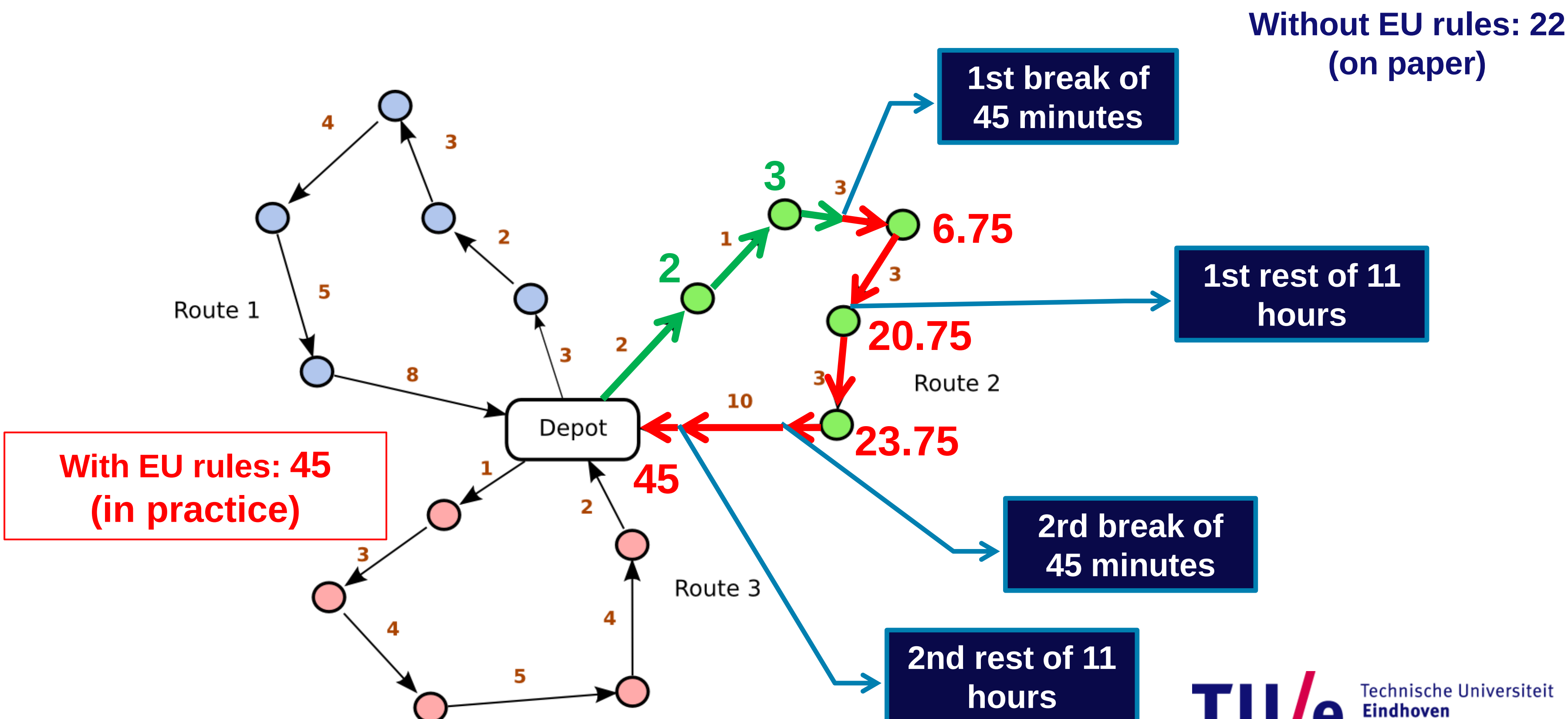
Act II: The challenges

Unrealistic transport plans violate EU regulations regarding driving and working time of drivers



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Act II: The challenges
Related literature

Source	Features of the studied problem	Solution Methodology
Goel A. (2009)	VS&RP with TW considering 2 weeks	A large neighborhood search
Goel A. (2010)	VS&RP with TW considering 1 week	A labeling algorithm
Prescott-Gagnon et al. (2010)	VRP with TW considering 1 week	A large neighborhood search using B&C algorithm to construct new neighbors
Kok et al. (2010)	VRP with TW considering all regulations	A restricted dynamic programming heuristic
Derigs et al. (2010)	Multi-trip VRP with TW considering 2 weeks	Decomposition approaches
Meyer (2011)	VSP with TW considering all regulations and distributed decision making	A restricted dynamic programming
Goel and Vidal (2013)	Vehicle Routing and Truck Driver Scheduling Problem	The Vidal nuclear bomb

Act III: Mathematical formulation

- **We have one….**
- **The model is verified with Gurobi for small instances**

Act IV: Solution Methodology

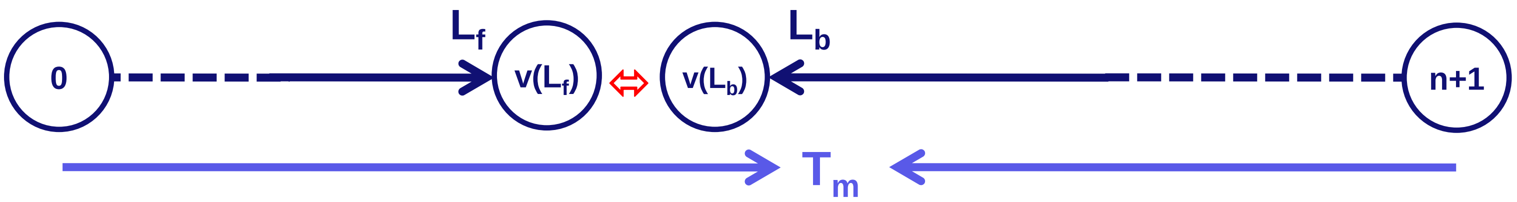
- **Master Problem: Set Partitioning, relaxed and solved by Column Generation.**
- **Pricing Sub-problem (labeling algorithm):**
  - **Elementary Shortest Path Problem with Resource Constraints (ESPPRC)**
  - **The additional resources:**
    - **Time (T)**
    - **Non-break time (T_{nb})**
    - **Non-rest time (T_{nr})**

Based on: Dabia, S., Röpke, S., Van Woensel, T. & de Kok, A.G. (2013). Branch and price for the time-dependent vehicle routing problem with time windows. Transportation Science, 47(3), 380-396

Act IV: Solution Methodology
Labeling algorithm

To improve its performance:

1. A bi-directional search was introduced where the labels are extended in both forward direction (from v_0 to its successors) and backward direction (from v_{n+1} to its predecessors).



2. ‘New’ dominance criteria were composed.

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Act IV: Solution Methodology
Weak Dominance Rules

Label L_f^2 is dominated by L_f^1 if:

1. $v(L_f^1) = v(L_f^2)$
2. $c(L_f^1) \leq c(L_f^2)$
3. $q(L_f^1) \leq q(L_f^2)$
4. $S(L_f^1) \subseteq S(L_f^2)$
5. $T(L_f^1) \leq T(L_f^2)$
6. $t_{nb}(L_f^1) \leq t_{nb}(L_f^2)$
7. $t_{nr}(L_f^1) \leq t_{nr}(L_f^2)$

Extra Resources

$v(L_f)$	as the last node visited by L_f,
$c(L_f)$	as the reduced negative cost of the partial path traversed by L_f,
$T(L_f)$	as the ready to service time at node $v(L_f)$ through the partial path traversed by L_f,
$q(L_f)$	as the accumulated load (summation of demands upto node $v(L_f)$) through the partial path traversed by L_f,
$t_{nb}(L_f)$	as the accumulated interval driving time from last break upto node $v(L_f)$,
$t_{nr}(L_f)$	as the accumulated daily driving time from last rest upto node $v(L_f)$,
$S(L_f)$	as the set of nodes visited along the partial path of label L_f.

Act IV: Solution Methodology
Improved Dominance Rules

Label L_f^2 is dominated by L_f^1 if:

1. $v(L_f^1) = v(L_f^2)$
2. $c(L_f^1) \leq c(L_f^2)$
3. $q(L_f^1) \leq q(L_f^2)$
4. $S(L_f^1) \subseteq \widetilde{S}(L_f^2)$

Set of visited nodes along partial path represented by label 2 extended by nodes that are unreachable from this node

5. Either of these 4 cases happens:

   (a) $t_{nb}(L_f^1) \leq t_{nb}(L_f^2)$ and $t_{nr}(L_f^1) \leq t_{nr}(L_f^2)$ and $T(L_f^1) \leq T(L_f^2)$

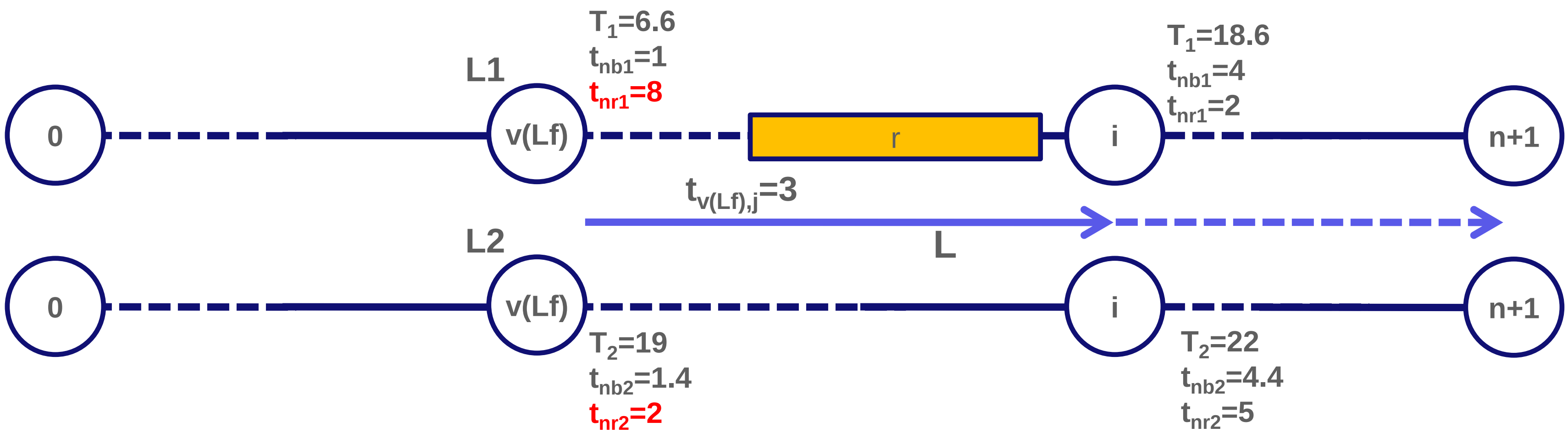
   (b) $t_{nb}(L_f^1) \geq t_{nb}(L_f^2)$ and $t_{nr}(L_f^1) \leq t_{nr}(L_f^2)$ and $T(L_f^1) \leq T(L_f^2) - b$

   (c) $t_{nb}(L_f^1) \leq t_{nb}(L_f^2)$ and $t_{nr}(L_f^1) \geq t_{nr}(L_f^2)$ and $T(L_f^1) \leq T(L_f^2) - r$

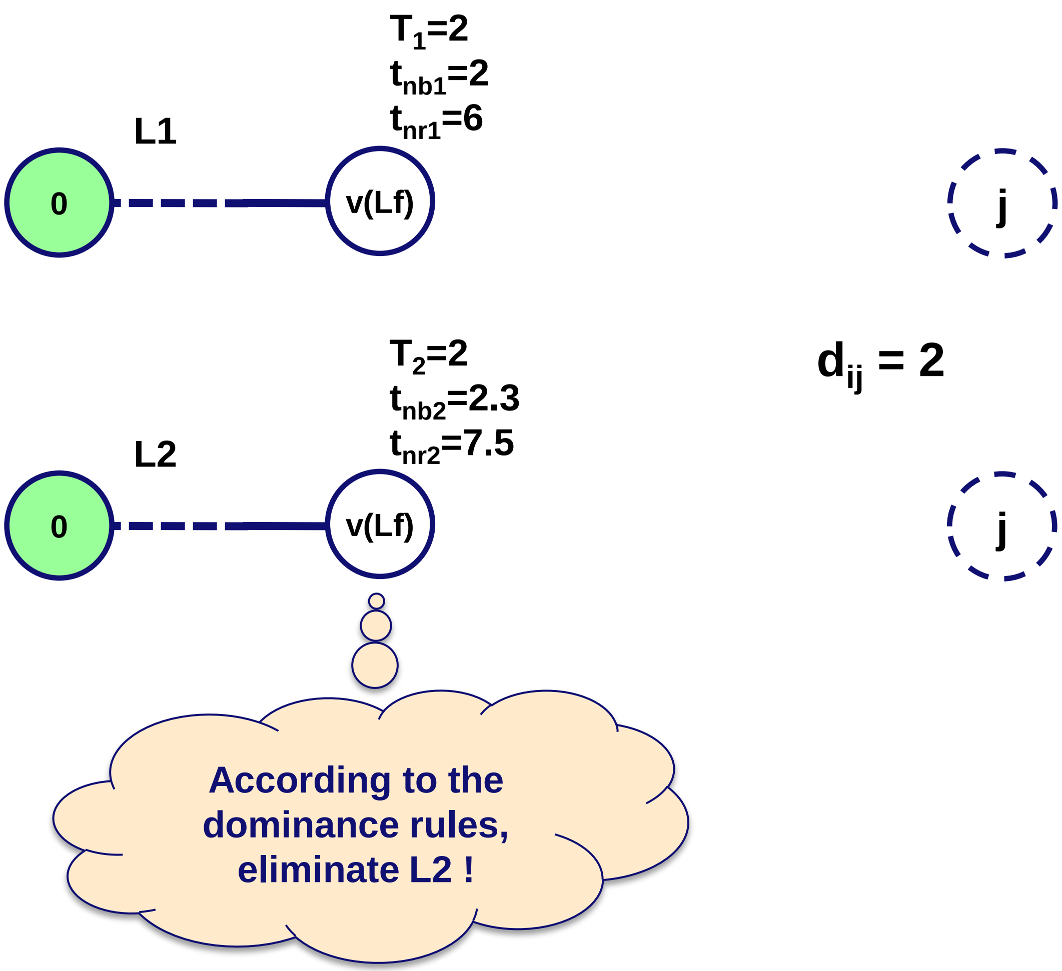
   (d) $t_{nb}(L_f^1) \geq t_{nb}(L_f^2)$ and $t_{nr}(L_f^1) \leq t_{nr}(L_f^2)$ and $T(L_f^1) \leq T(L_f^2) - b - r$

Act IV: Solution Methodology
Improved Dominance Rules (an illustration)

(c) $t_{nb}(L_f^1) \leq t_{nb}(L_f^2)$ and $t_{nr}(L_f^1) \geq t_{nr}(L_f^2)$ and $Ta(L_f^1) \leq T(L_f^2) - r$

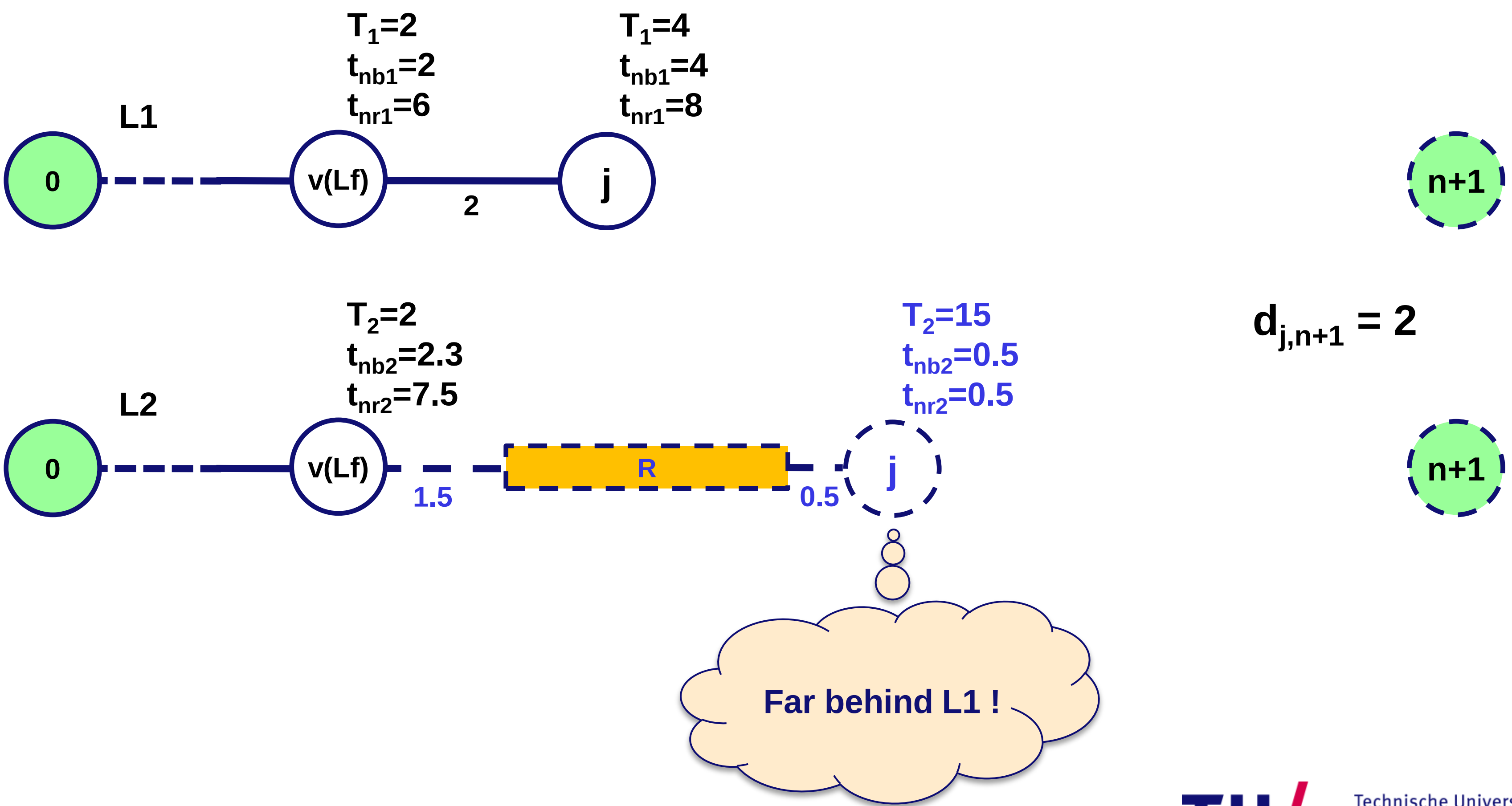


Act IV: Solution Methodology
The danger of using these dominance rules

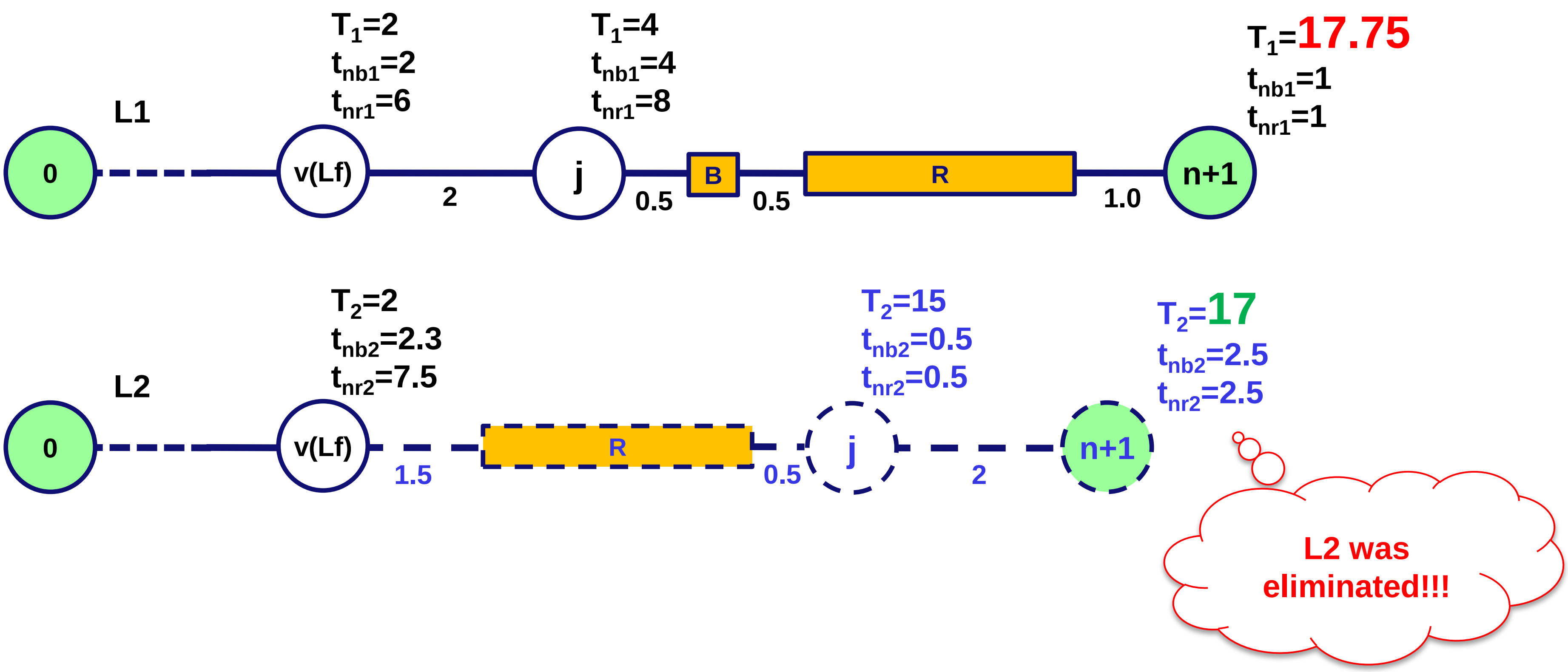


Act IV: Solution Methodology

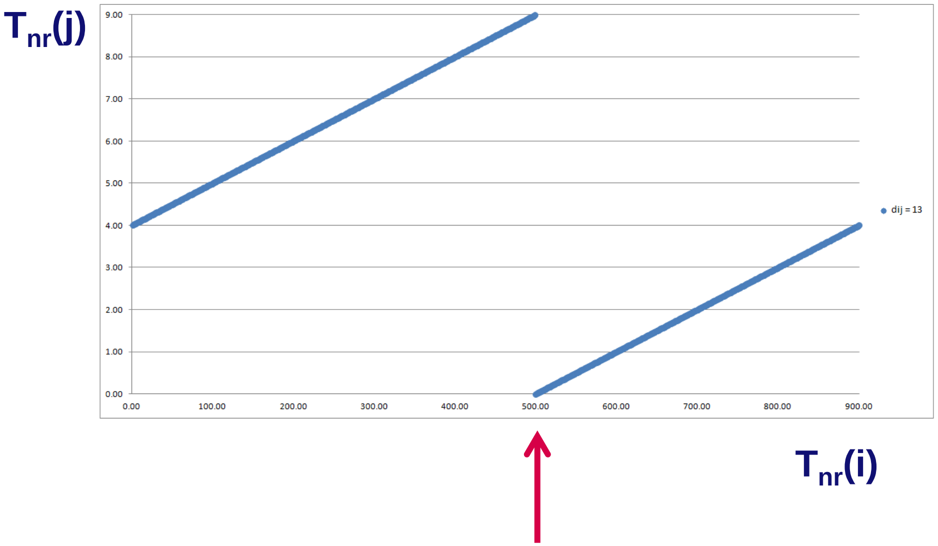
The danger of using these dominance rules

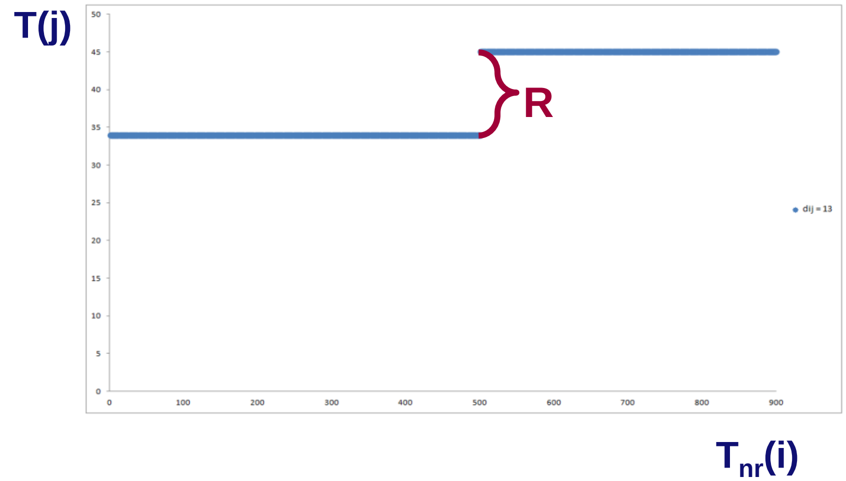


Act IV: Solution Methodology
The danger of using these dominance rules



Act IV: Solution Methodology
Non-Monotonic Behavior of t_{nb} and t_{nr} (forward extension)





Some solutions tested/being tested:

- Create more labels (nothing/rest/break)
- Create more nodes (rest/break nodes)

Act V: Computational results Solomon 15 customers

	Mono-		Bi-	
	Time	OFV	Time	OFV
c101-15	0.686	14,208	0.094	14,208
r101-15	0.219	35,560	0.124	35,560
rc101-15	0.405	21,601	0.187	21,601
c102-15	6.879	14,100	>1 hour	n/a
r102-15	2.542	31,006	>1 hour	n/a
rc102-15	13.728	19,215	>1 hour	n/a
c106-15	0.717	14,208	0.187	14,208

Act V: Computational results
Computational Results

- **Tested:**
  - **15- and 25-customer instances of standard Solomon C, R, and RC series for VRPTW**
- **Objective Function including the regulations:**
  - **Increased around 15% more compared to pure VRPTW**
- **Strong Dominance:**
  - **Reduced more labels compared to the weak dominance**
  - **Reduced run-time up to 29.80%**

Epilogue: All’s well but… What happens in practice?

- Usually no optimization (PTV, ORTEC)
- Planners:
  - Experience, experience, experience
  - After the route planning, some eyeballing (parking spaces)
  - Take into account more features
- Subcontract:
  - Not your problem anymore…
- World is much more interesting:
  - Uncertainty, stochasticity, time-dependency, exceptions => data
- Probably other “models” needed

Epilogue: *All's Well That Ends Well*
Conclusions and future directions

- **Break regulations is needed to be taken into account and are enforced by governments!**
- **A *formal compact* model of the break regulations in a VRPTW is provided.**
- **Exact solution technique is presented**

- **Future Research:**
  - **Speeding up the algorithm**
  - **Benchmarking with the heuristic based results in the literature**
  - ***Complete legislation rules in the model***

Epilogue

Thank you for your attention!

Questions?