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Preventing delays via in-advance linac capacity planning.

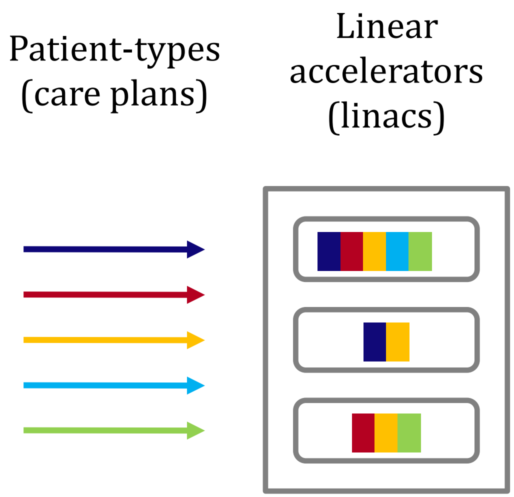
Arturo E. Pérez Rivera

NKI-AVL
The Netherlands Cancer Institute
Antoni van Leeuwenhoek Hospital

INTRODUCTION

Arturo E. Pérez Rivera

- **Industrial Engineering** at the University of Twente.
- *PhD student at the NKI-AVL, in the Radiotherapy Department.*



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AGENDA

Preventing delays via proactive linac-capacity planning.

- When can capacity planning go wrong?
- What can we do about it?
- What benefits can in-advance planning have?
- Conclusions

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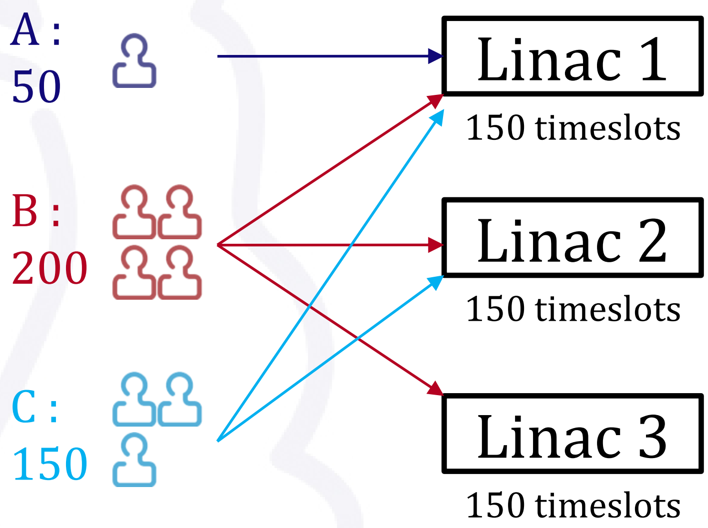
WHEN CAN CAPACITY PLANNING GO WRONG?

A small example…



Demand = 400 patients
Supply = 450 linac-timeslots
Demand/Supply Ratio = 89%

If all patients arrive at the same time:

Care Plan →	A	B	C	Total	Unused Cap.
Linac 1	50	100	-	**150**	**0**
Linac 2	-	-	150	**150**	**0**
Linac 3	-	100	-	**100**	***-50***
Started	**50**	**200**	**150**	**400**	**-**
Delayed	**0**	**0**	**0**	**0**	**-**

If all 'B' arrive 1st, 'A' 2nd and 'C' 3rd:

Care Plan →	A	B	C	Total	Unused Cap.
Linac 1	-	150	-	**150**	**0**
Linac 2	-	50	100	**150**	**0**
Linac 3	-	-	-	**100**	***-150***
Started	**0**	**200**	**100**	**400**	**-**
Delayed	***-50***	**0**	***-50***	***-100***	**-**

WHEN CAN CAPACITY PLANNING GO WRONG?

Our hypotheses…

When there is:

- High uncertainty in the day-to-day arrival of all patients
- Highly constrained group of linacs
- High 'demand/supply' ratio

In the NKI-AVL:

- One care plan has 1 and other 1300 patients per year.
- Some care plans can be treated in 2 and others in 8 linacs.
- Patient-fractions use 90% of the linac-time per year.

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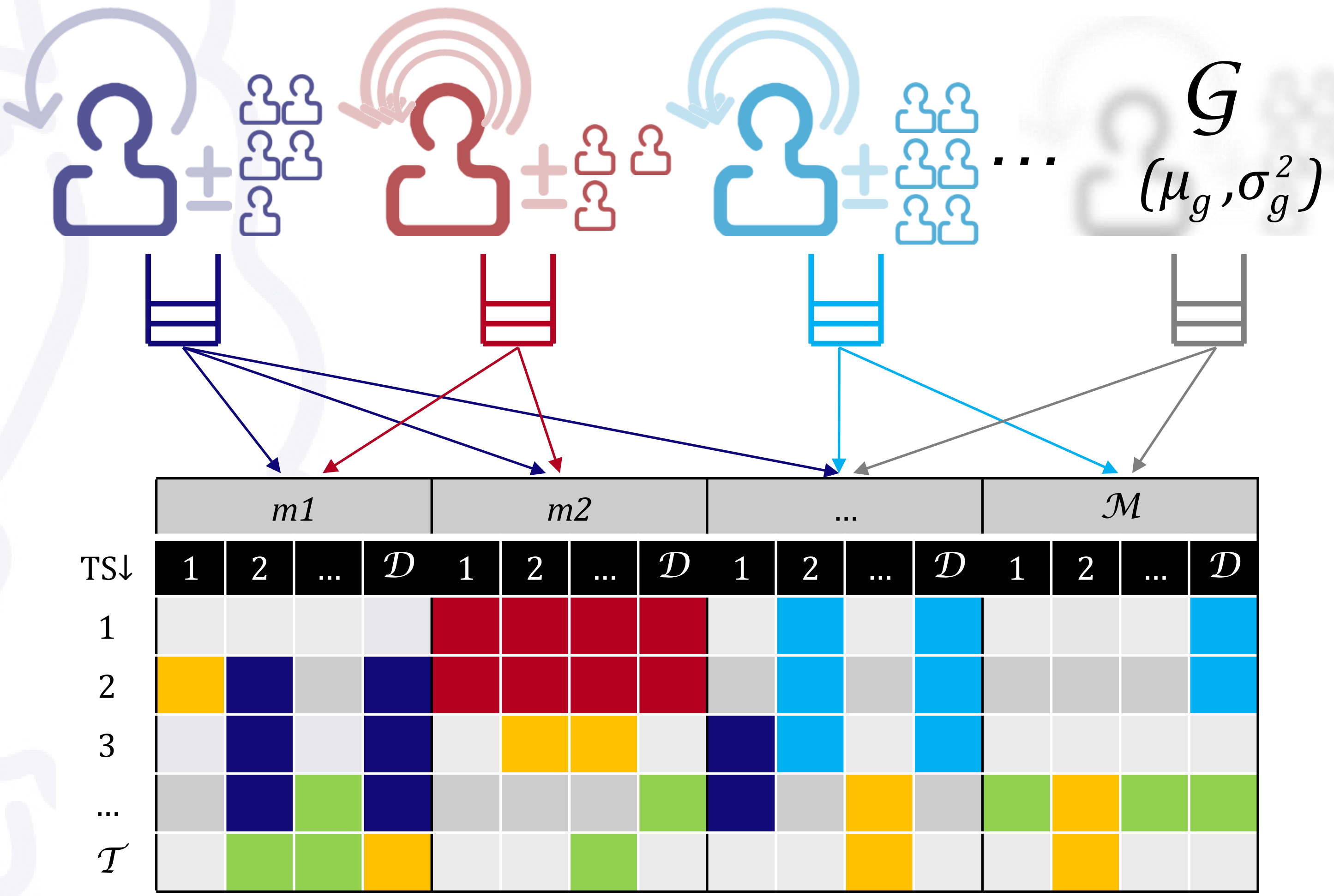
WHAT CAN WE DO ABOUT IT?

A combinatorial optimization model [1/2]:



s_g

α_g

$f_{g,m} \in \{0,1\}$

$m \in \mathcal{M}$
$t \in \mathcal{T}$
$d \in \mathcal{D}$

$V_{g,m} \in \mathbb{N}$

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WHAT CAN WE DO ABOUT IT?

A combinatorial optimization model [2/2]:

$$\min Z = \sum_{g \in \mathcal{G}} \alpha_g \cdot \underbrace{\mathbb{E}^{\mathcal{D}}\left[\mathcal{F}_g(x)\right]}_{Unclosed\ form}$$

$$x = \begin{bmatrix} V_{1,1} & V_{1,2} & \cdots & V_{1,m} \\ V_{2,1} & V_{2,2} & \cdots & V_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ V_{g,1} & V_{g,2} & \cdots & V_{g,m} \end{bmatrix}$$

$$x \in \mathcal{X}$$

$$\mathcal{O}(w) = \sum_{g \in \mathcal{G}} \left[\alpha_g^{wait} \cdot \sum_{p \in w} \left(\underbrace{\sum_d (d - a_p) \cdot b_{p,g} \cdot X_{p,d}^{start}}_{Access\ time\ of\ patient\ p} \right) \right]$$

s.t.

$$\sum_g \sum_p \sum_t b_{p,g} \cdot X_{p,m,t,d} \leq V_{g,m} \quad \forall m, d$$

$$X_{p,m,t,d} \leq f_{g,m} \quad \forall m, t, d, p, g | b_{p,g} = 1$$

$$\sum_p X_{p,m,t,d} + \sum_q r_{q,m,t,d} \leq 1 \quad \forall m, t, d$$

$$\sum_{m,t} X_{p,m,t,d} \leq 1 \quad \forall p, d$$

$$\sum_{m,t,d} X_{p,m,t,d} = s_g \cdot \sum_d X_{p,d}^{start} \quad \forall p, g | b_{p,g} = 1$$

$$\sum_{t,d} X_{p,m,t,d} \leq s_g \cdot X_{p,m}^{linac} \quad \forall m, p, g | b_{p,g} = 1$$

$$\sum_{m' \in \mathcal{M} \setminus \{m\}, t, d} X_{p,m',t,d} \leq s_g \cdot (1 - X_{p,m}^{linac}) \quad \forall m, p, g | b_{p,g} = 1$$

$$\sum_d X_{p,d}^{start} \leq 1 \quad \forall p$$

$$\sum_{d'=d}^{d+s_g-1} \sum_{m,t} X_{p,m,t,d'} \geq s_g \cdot X_{p,d}^{start} \quad \forall p, d, g | b_{p,g} = 1$$

$$All\ X_{p,m,t,d}, X_{p,d}^{start}, X_{p,m}^{linac} \in \{0,1\}$$

What we can do is:

- Translate the process into mathematical programming,
- Solve the model (!) to get a good plan.

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WHAT CAN WE DO ABOUT IT?

In a nutshell…

- Allocate capacity in advance *(tactical planning)* such that the expected access time is minimized.

ProaRT

Preventing delays via proactive linac-capacity planning.

Tactical allocation (ProaRT's table):

Patients	Linac 1	Linac 2	Linac 3
Type 1	25	16	7
Type 2	12	0	10
Type 3	8	3	17
Type 4	12	0	18
Type 5	6	5	14

→ *ProaRT's operational scheduling:*

- A patient is scheduled, upon arrival, in the *earliest* available linac that:

(1) is treating less patients than the *maximum given by ProaRT's table,*

(2) has the least patients (from all types) planned compared to other linacs.

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WHAT BENEFITS CAN IN-ADVANCE PLANNING HAVE?

Our theoretical experiments

Three levels:

- **(C) Critical**
- **(N) Normal** *(NKI-AVL based)*→
- **(R) Relaxed**

All levels:

- 16 categories
- 8 linacs

On the normal level:

- Linac feasibility of 63%
- Demand/Supply ratio of 89%
- Patient-fraction distribution of 2x15%,4x10%,10x3%

Performance:

Weighted sum of access times for a year.

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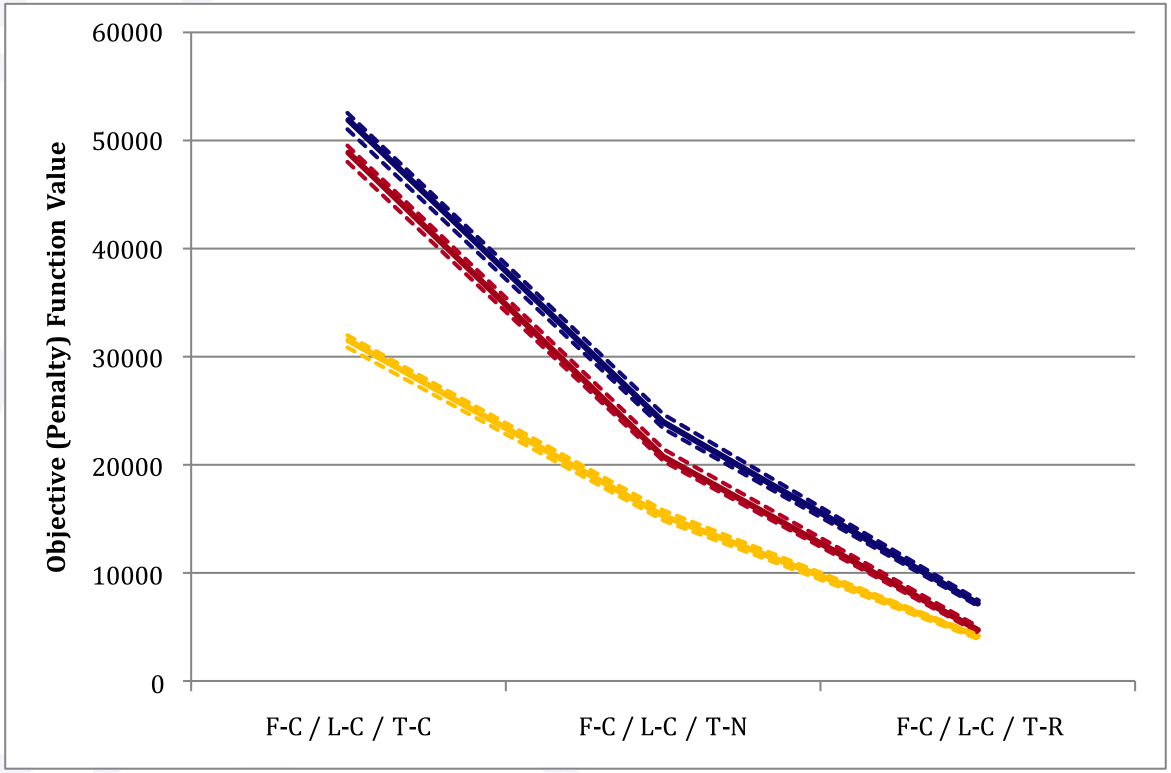
WHAT BENEFITS CAN IN-ADVANCE PLANNING HAVE?

Our theoretical results [1/2]



Timeslots: **-2** **Nominal** **+2**

■ OAS (current) ■ BWS ■ ProaRT (planning in-advance)

- *Critical* Linacs (L-C):

  Patients can be treated, on average, in 50% of the linacs.

- *Critical* Fractions (F-C):

  80% of the total fractions given are to 20% of the care plans (patient-types).

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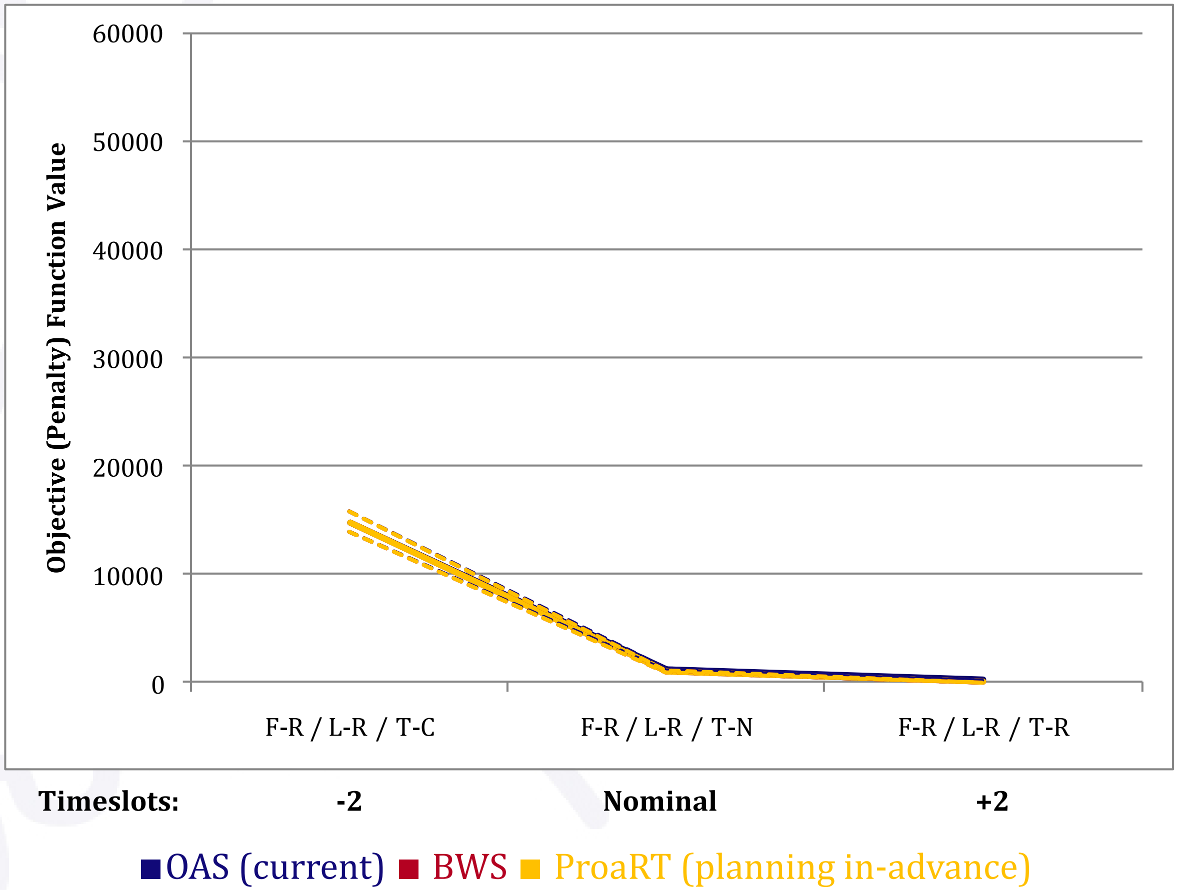
WHAT BENEFITS CAN IN-ADVANCE PLANNING HAVE?

Our theoretical results [2/2]



- *Relaxed* Linacs (L-R):

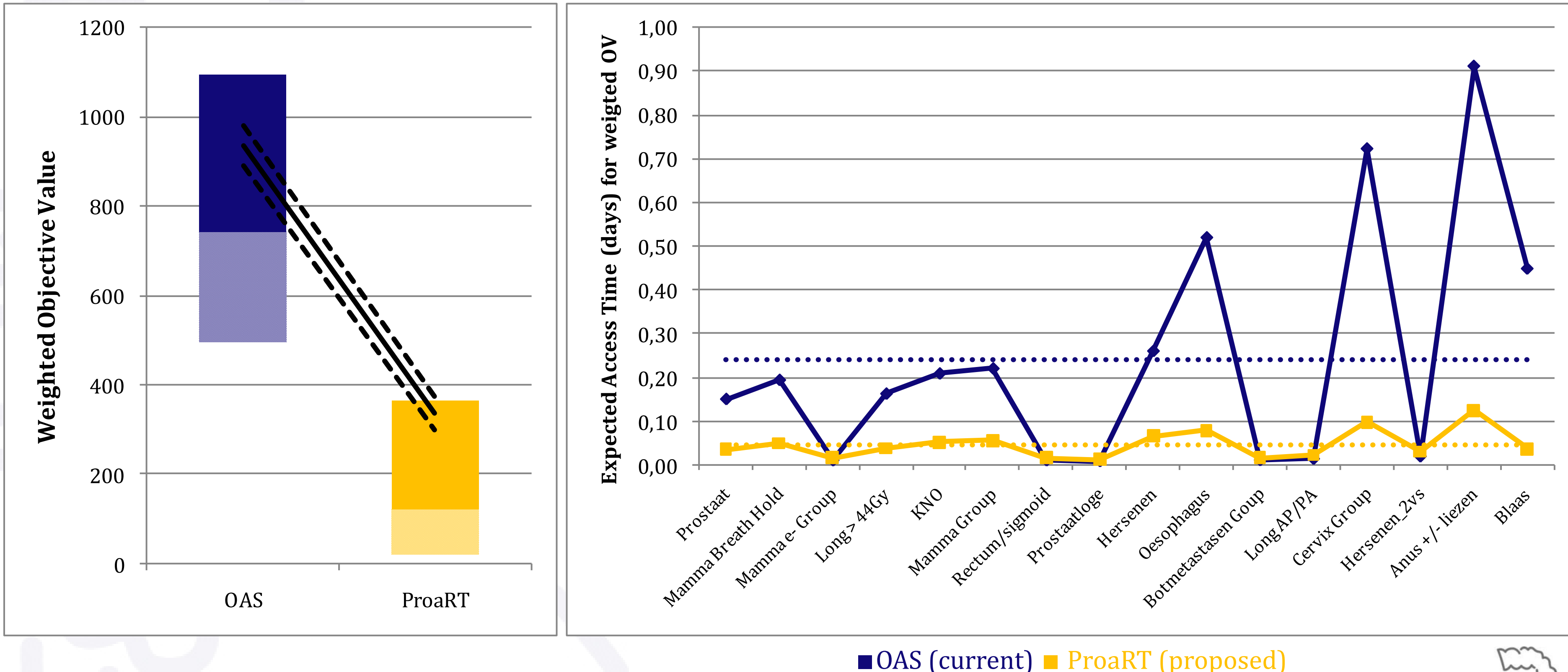
  Patients can be treated, on average, in 75% of the linacs..

- *Relaxed* Fractions (F-R):

  All care plans have the same total fractions given.

WHAT BENEFITS CAN IN-ADVANCE PLANNING HAVE?

Current situation in the NKI-AVL



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CONCLUSIONS

Delays can be prevented by planning in-advance (e.g. via ProoaRT).

- For 'critical' and large radiotherapy departments, planning in-advance makes a significant and positive difference.

- On average, linac-capacity is not the bottleneck at the NKI-AVL's RT Process (access time is of 0.24 days). Nevertheless, planning it in-advance can help decrease access time for the current (down to 0.05 days) and future situations.

- Further logistical research in the entire chain of the radiotherapy process can *help cancer patients get treated at the earliest opportunity.*

Wetenschappelijke Kringdag
Kring Klinische Fysica Radiotherapie
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Amsterdam, the Netherlands

Thanks for your attention!

Arturo E. Pérez Rivera

PhD student at NKI-AVL
T: +31 20 512 9033
E: a.perez@nki.nl

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Antoni van Leeuwenhoek Hospital

Questions?

Arturo E. Pérez Rivera
PhD student at NKI-AVL
T: +31 20 512 9033
E: a.perez@nki.nl