ACM Transactions on Software Engineering and Methodology (TOSEM) 2018

LINEAR PROGRAMMING AS A BASELINE FOR EFFORT ESTIMATION (LP4EE)

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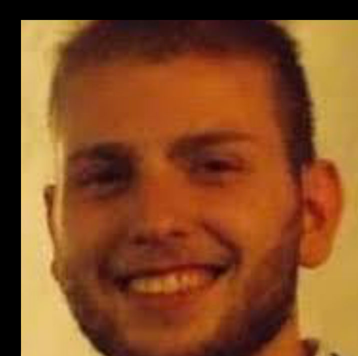

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baseline | ˈbeɪslʌɪn |

noun

1 a minimum or starting point used for comparisons.

2 (in tennis, volleyball, and other games) the line marking each end of a court.

3 *Baseball* the line between bases which a runner must stay close to when running.

4 *Printing* the imaginary straight line through the feet of most letters in a line of type.

Picture from https://www.liquidartsystem.com/en/a/giacinto-bosco

Conclusion Instability

A BASELINE MODEL FOR SOFTWARE EFFORT ESTIMATION

Whigham et al. TOSEM 2015

Be **simple** to describe, implement, and interpret

Be **deterministic** in its outcomes

Be applicable to mixed **qualitative** and **quantitative data**

Offer some **explanatory** information regarding the prediction

Have **no parameters** within the modelling process that require **tuning**

Be **publicly available** (reference implementation and environment)

Be more **accurate** than random guess or response variable based estimates

Automatically Transformed Linear Model (ATLM)

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Sarro and Petrozziello TOSEM 2018

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Be **robust** to different data splits and validation methods

WHY A ROBUST BASELINE? WE WANT TO AVOID…

A novel estimation method M is proposed

It is benchmarked against a baseline model B

The validation method V and the data split D are used

M outperforms B only for this particular instance of V and D

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Do **not** be **expensive** to apply

Offer **comparable** performance **to standard methods**

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LP4EE: Linear Programming for Effort Estimation

LP4EE + EMPIRICAL STUDY

Does LP4EE (ATLM) satisfy the requirements for a baseline model?

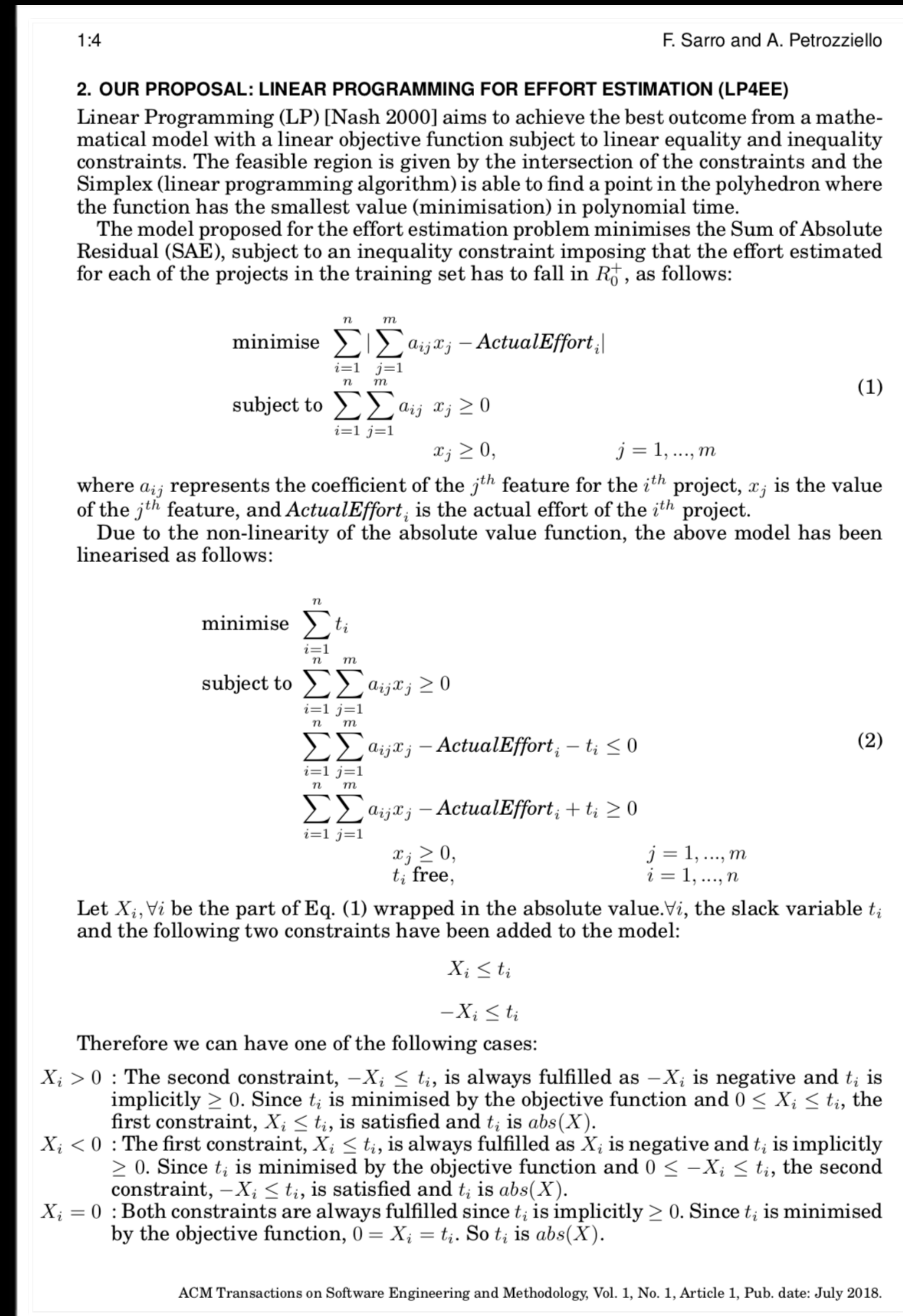
Is LP4EE (ATLM) effective to benchmark state-of-the-art estimators?

4 estimation methods (CART, KNN, RF, SVR) vs. LP and ATLM

10 industrial datasets publicly available

4 cross-validation methods (3-fold, 5-fold, 10-fold, LOO)

30 runs (each with a different data split)



1:4 F. Sarro and A. Petrozziello

2. OUR PROPOSAL: LINEAR PROGRAMMING FOR EFFORT ESTIMATION (LP4EE)

Linear Programming (LP) [Nash 2000] aims to achieve the best outcome from a mathematical model with a linear objective function subject to linear equality and inequality constraints. The feasible region is given by the intersection of the constraints and the Simplex (linear programming algorithm) is able to find a point in the polyhedron where the function has the smallest value (minimisation) in polynomial time.

The model proposed for the effort estimation problem minimises the Sum of Absolute Residual (SAE), subject to an inequality constraint imposing that the effort estimated for each of the projects in the training set has to fall in R_0^+, as follows:

$$
\begin{aligned}
\text{minimise} \quad & \sum_{i=1}^{n} \Big| \sum_{j=1}^{m} a_{ij} x_j - \mathit{ActualEffort}_i \Big| \\
\text{subject to} \quad & \sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij} \ x_j \geq 0 \\
& x_j \geq 0, \qquad\qquad j = 1, ..., m
\end{aligned} \tag{1}
$$

where a_{ij} represents the coefficient of the j^{th} feature for the i^{th} project, x_j is the value of the j^{th} feature, and $\mathit{ActualEffort}_i$ is the actual effort of the i^{th} project.

Due to the non-linearity of the absolute value function, the above model has been linearised as follows:

$$
\begin{aligned}
\text{minimise} \quad & \sum_{i=1}^{n} t_i \\
\text{subject to} \quad & \sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij} x_j \geq 0 \\
& \sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij} x_j - \mathit{ActualEffort}_i - t_i \leq 0 \\
& \sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij} x_j - \mathit{ActualEffort}_i + t_i \geq 0 \\
& x_j \geq 0, \qquad\qquad j = 1, ..., m \\
& t_i \text{ free}, \qquad\qquad i = 1, ..., n
\end{aligned} \tag{2}
$$

Let $X_i, \forall i$ be the part of Eq. (1) wrapped in the absolute value.$\forall i$, the slack variable t_i and the following two constraints have been added to the model:

$$X_i \leq t_i$$

$$-X_i \leq t_i$$

Therefore we can have one of the following cases:

$X_i > 0$: The second constraint, $-X_i \leq t_i$, is always fulfilled as $-X_i$ is negative and t_i is implicitly ≥ 0. Since t_i is minimised by the objective function and $0 \leq X_i \leq t_i$, the first constraint, $X_i \leq t_i$, is satisfied and t_i is $abs(X)$.

$X_i < 0$: The first constraint, $X_i \leq t_i$, is always fulfilled as X_i is negative and t_i is implicitly ≥ 0. Since t_i is minimised by the objective function and $0 \leq -X_i \leq t_i$, the second constraint, $-X_i \leq t_i$, is satisfied and t_i is $abs(X)$.

$X_i = 0$: Both constraints are always fulfilled since t_i is implicitly ≥ 0. Since t_i is minimised by the objective function, $0 = X_i = t_i$. So t_i is $abs(X)$.

ACM Transactions on Software Engineering and Methodology, Vol. 1, No. 1, Article 1, Pub. date: July 2018.

STANDARDISED ACCURACY RESULTS

		AK	China	Desh.	Finnish	Kitche.	Maxw.	Myaz.	Nasa	Nasa93	Telec.
Baseline	**LP4EE**	0.48	**0.49**	**0.47**	0.41	**0.66**	**0.54**	**0.54**	**0.11**	**0.58**	0.38
	ATLM	**0.51**	0.32	0.43	0.46	0.20	0.50	0.49	-0.35	**0.58**	0.37
State of the art	**CART**	0.35	0.39	0.36	0.43	0.22	0.46	0.20	0.06	0.44	0.32
	KNN	0.44	0.46	0.44	0.43	0.45	0.50	0.45	0.05	0.47	0.30
	RF	0.41	0.45	0.43	**0.48**	0.40	0.51	0.53	0.11	0.53	0.41
	SVR	0.42	0.44	0.41	0.41	0.38	0.49	0.40	0.09	0.51	**0.42**

**statistical significance test and effect size results an be found in the paper*

ROBUSTNESS TO DIFFERENT DATA SPLITS

Best estimation method per dataset when ATLM (a) or LP4EE (b) are used as a benchmark for each data split

	AK		China		Desharnais		Finnish		Maxwell		Miyazaki		Kitchenam		Nasa		Nasa93Coc		Telecom	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Split1	ATLM	LP4EE	KNN10	LP4EE	KNN10	KNN10	RF	RF	ATLM	LP4EE	ATLM	LP4EE	RF	RF	KNN1	KNN1	ATLM	LP4EE	KNN1	KNN1
Split2	ATLM	LP4EE	RF	LP4EE	ATLM	LP4EE	ATLM	CART	ATLM	LP4EE	ATLM	LP4EE	RF	LP4EE	KNN1	LP4EE	ATLM	LP4EE	RF	RF
Split3	ATLM	LP4EE	KNN10	LP4EE	RF	RF	RF	RF	ATLM	LP4EE	ATLM	LP4EE	ATLM	RF	SVR	SVR	ATLM	LP4EE	RF	RF
Split4	ATLM	LP4EE	KNN10	LP4EE	KNN10	KNN10	ATLM	LP4EE	ATLM	LP4EE	KNN10	KNN10	RF	RF	RF	RF	RF	LP4EE	RF	LP4EE
Split5	ATLM	KNN10	KNN10	LP4EE	KNN10	KNN10	ATLM	RF	ATLM	LP4EE	ATLM	LP4EE	RF	LP4EE	SVR	LP4EE	ATLM	LP4EE	SVR	SVR
Split6	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	SVR	SVR	ATLM	LP4EE	RF	LP4EE	RF	LP4EE	KNN1	LP4EE	RF	LP4EE	RF	LP4EE
Split7	ATLM	LP4EE	KNN10	LP4EE	ATLM	LP4EE	CART	CART	ATLM	LP4EE	ATLM	RF	ATLM	LP4EE	RF	RF	ATLM	RF	KNN1	KNN1
Split8	ATLM	KNN10	KNN10	LP4EE	RF	LP4EE	RF	RF	ATLM	LP4EE	KNN10	LP4EE	ATLM	RF	RF	RF	ATLM	RF	RF	LP4EE
Split9	ATLM	LP4EE	KNN10	LP4EE	ATLM	LP4EE	RF	RF	ATLM	LP4EE	ATLM	LP4EE	RF	LP4EE	RF	RF	ATLM	LP4EE	ATLM	KNN1
Split10	ATLM	LP4EE	KNN10	LP4EE	ATLM	LP4EE	ATLM	CART	ATLM	LP4EE	ATLM	LP4EE	RF	LP4EE	KNN1	KNN1	ATLM	LP4EE	SVR	SVR
Split11	SVR	SVR	KNN10	LP4EE	RF	LP4EE	ATLM	RF	ATLM	LP4EE	KNN10	LP4EE	RF	LP4EE	SVR	LP4EE	RF	LP4EE	ATLM	RF
Split12	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	RF	RF	ATLM	LP4EE	RF	LP4EE	ATLM	LP4EE	KNN1	LP4EE	ATLM	LP4EE	SVR	SVR
Split13	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	ATLM	KNN10	ATLM	LP4EE	ATLM	LP4EE	ATLM	LP4EE	KNN1	KNN1	ATLM	RF	SVR	SVR
Split14	ATLM	LP4EE	KNN10	LP4EE	ATLM	LP4EE	RF	RF	ATLM	LP4EE	ATLM	LP4EE	ATLM	LP4EE	KNN10	LP4EE	RF	RF	RF	LP4EE
Split15	ATLM	LP4EE	RF	LP4EE	ATLM	LP4EE	RF	RF	ATLM	LP4EE	ATLM	RF	RF	LP4EE	KNN1	KNN1	ATLM	LP4EE	KNN1	KNN1
Split16	ATLM	LP4EE	RF	LP4EE	KNN10	LP4EE	RF	RF	ATLM	LP4EE	ATLM	LP4EE	ATLM	LP4EE	RF	RF	RF	LP4EE	RF	RF
Split17	ATLM	LP4EE	KNN10	LP4EE	RF	RF	RF	RF	KNN10	LP4EE	CART	CART	ATLM	LP4EE	RF	RF	ATLM	LP4EE	SVR	SVR
Split18	ATLM	LP4EE	KNN10	LP4EE	RF	LP4EE	RF	RF	ATLM	LP4EE	ATLM	LP4EE	ATLM	LP4EE	SVR	LP4EE	ATLM	LP4EE	RF	LP4EE
Split19	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	RF	RF	ATLM	LP4EE	KNN10	LP4EE	ATLM	LP4EE	KNN10	LP4EE	SVR	LP4EE	SVR	SVR
Split20	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	ATLM	RF	ATLM	LP4EE	SVR	LP4EE	RF	LP4EE	KNN1	KNN1	SVR	LP4EE	SVR	SVR
Split21	ATLM	LP4EE	RF	LP4EE	ATLM	LP4EE	ATLM	SVR	ATLM	LP4EE	CART	LP4EE	RF	LP4EE	KNN1	LP4EE	SVR	LP4EE	KNN1	KNN1
Split22	ATLM	LP4EE	KNN10	LP4EE	ATLM	LP4EE	RF	RF	ATLM	LP4EE	ATLM	LP4EE	RF	LP4EE	KNN1	LP4EE	ATLM	LP4EE	RF	RF
Split23	ATLM	LP4EE	KNN10	LP4EE	KNN10	KNN10	RF	RF	ATLM	LP4EE	ATLM	LP4EE	RF	RF	SVR	SVR	ATLM	LP4EE	SVR	SVR
Split24	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	RF	RF	ATLM	LP4EE	CART	CART	ATLM	LP4EE	RF	LP4EE	RF	RF	RF	RF
Split25	ATLM	LP4EE	RF	LP4EE	ATLM	LP4EE	CART	CART	ATLM	LP4EE	ATLM	RF	ATLM	RF	RF	LP4EE	ATLM	LP4EE	SVR	SVR
Split26	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	ATLM	RF	ATLM	LP4EE	RF	LP4EE	RF	LP4EE	KNN1	KNN1	RF	LP4EE	SVR	LP4EE
Split27	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	RF	RF	ATLM	LP4EE	ATLM	LP4EE	ATLM	RF	RF	RF	ATLM	LP4EE	SVR	LP4EE
Split28	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	RF	RF	ATLM	LP4EE	CART	LP4EE	ATLM	LP4EE	SVR	LP4EE	ATLM	LP4EE	SVR	SVR
Split29	ATLM	LP4EE	KNN10	LP4EE	RF	LP4EE	RF	RF	ATLM	LP4EE	KNN10	LP4EE	ATLM	RF	SVR	SVR	ATLM	LP4EE	ATLM	RF
Split30	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	ATLM	SVR	ATLM	LP4EE	RF	RF	RF	RF	RF	RF	ATLM	LP4EE	CART	LP4EE

ROBUSTNESS TO DIFFERENT DATA SPLITS

	Desharnais		Finnish		Maxwell		Miyazaki		Kitchenam		Nasa	
)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
P4EE	KNN10	KNN10	RF	RF	ATLM	LP4EE	ATLM	LP4EE	RF	RF	KNN1	KNN
P4EE	ATLM	LP4EE	ATLM	CART	ATLM	LP4EE	ATLM	LP4EE	RF	LP4EE	KNN1	LP4E
P4EE	RF	RF	RF	RF	ATLM	LP4EE	ATLM	LP4EE	ATLM	RF	SVR	SVR
P4EE	KNN10	KNN10	ATLM	LP4EE	ATLM	LP4EE	KNN10	KNN10	RF	RF	RF	RF
P4EE	KNN10	KNN10	ATLM	RF	ATLM	LP4EE	ATLM	LP4EE	RF	LP4EE	SVR	LP4E
P4EE	KNN10	LP4EE	SVR	SVR	ATLM	LP4EE	RF	LP4EE	RF	LP4EE	KNN1	LP4E
P4EE	ATLM	LP4EE	CART	CART	ATLM	LP4EE	ATLM	RF	ATLM	LP4EE	RF	RF
P4EE	RF	LP4EE	RF	RF	ATLM	LP4EE	KNN10	LP4EE	ATLM	RF	RF	RF
P4EE	ATLM	LP4EE	RF	RF	ATLM	LP4EE	ATLM	LP4EE	RF	LP4EE	RF	RF
P4EE	ATLM	LP4EE	ATLM	CART	ATLM	LP4EE	ATLM	LP4EE	RF	LP4EE	KNN1	KNN
P4EE	RF	LP4EE	ATLM	RF	ATLM	LP4EE	KNN10	LP4EE	RF	LP4EE	SVR	LP4E
P4EE	KNN10	LP4EE	RF	RF	ATLM	LP4EE	RF	LP4EE	ATLM	LP4EE	KNN1	LP4E
P4EE	KNN10	LP4EE	ATLM	KNN10	ATLM	LP4EE	ATLM	LP4EE	ATLM	LP4EE	KNN1	KNN
P4EE	ATLM	LP4EE	RF	RF	ATLM	LP4EE	ATLM	LP4EE	ATLM	LP4EE	KNN10	LP4E
P4EE	ATLM	LP4EE	RF	RF	ATLM	LP4EE	ATLM	RF	RF	LP4EE	KNN1	KNN
P4EE	KNN10	LP4EE	RF	RF	ATLM	LP4EE	ATLM	LP4EE	ATLM	LP4EE	RF	RF
P4EE	RF	RF	RF	RF	KNN10	LP4EE	CART	CART	ATLM	LP4EE	RF	RF
P4EE	RF	LP4EE	RF	RF	ATLM	LP4EE	ATLM	LP4EE	ATLM	LP4EE	SVR	LP4E
P4EE	KNN10	LP4EE	RF	RF	ATLM	LP4EE	KNN10	LP4EE	ATLM	LP4EE	KNN10	LP4E
P4EE	KNN10	LP4EE	ATLM	RF	ATLM	LP4EE	SVR	LP4EE	RF	LP4EE	KNN1	KNN
P4EE	ATLM	LP4EE	ATLM	SVR	ATLM	LP4EE	CART	LP4EE	RF	LP4EE	KNN1	LP4E
P4EE	ATLM	LP4EE	RF	RF	ATLM	LP4EE	ATLM	LP4EE	RF	LP4EE	KNN1	LP4E
P4EE	KNN10	KNN10	RF	RF	ATLM	LP4EE	ATLM	LP4EE	RF	RF	SVR	SVR
P4EE	KNN10	LP4EE	RF	RF	ATLM	LP4EE	CART	CART	ATLM	LP4EE	RF	LP4E
P4EE	ATLM	LP4EE	CART	CART	ATLM	LP4EE	ATLM	RF	ATLM	RF	RF	LP4E
P4EE	KNN10	LP4EE	ATLM	RF	ATLM	LP4EE	RF	LP4EE	RF	LP4EE	KNN1	KNN
P4EE	KNN10	LP4EE	RF	RF	ATLM	LP4EE	ATLM	LP4EE	ATLM	RF	RF	RF
P4EE	KNN10	LP4EE	RF	RF	ATLM	LP4EE	CART	LP4EE	ATLM	LP4EE	SVR	LP4E
P4EE	RF	LP4EE	RF	RF	ATLM	LP4EE	KNN10	LP4EE	ATLM	RF	SVR	SVR
P4EE	KNN10	LP4EE	ATLM	SVR	ATLM	LP4EE	RF	RF	RF	RF	RF	RF

ROBUSTNESS TO DIFFERENT DATA SPLITS

	AK		China		Desharnais		Finnish		Maxwell	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Split1	ATLM	LP4EE	KNN10	LP4EE	KNN10	KNN10	RF	RF	ATLM	LP4E
Split2	ATLM	LP4EE	RF	LP4EE	ATLM	LP4EE	ATLM	CART	ATLM	LP4E
Split3	ATLM	LP4EE	KNN10	LP4EE	RF	RF	RF	RF	ATLM	LP4E
Split4	ATLM	LP4EE	KNN10	LP4EE	KNN10	KNN10	ATLM	LP4EE	ATLM	LP4E
Split5	ATLM	KNN10	KNN10	LP4EE	KNN10	KNN10	ATLM	RF	ATLM	LP4E
Split6	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	SVR	SVR	ATLM	LP4E
Split7	ATLM	LP4EE	KNN10	LP4EE	ATLM	LP4EE	CART	CART	ATLM	LP4E
Split8	ATLM	KNN10	KNN10	LP4EE	RF	LP4EE	RF	RF	ATLM	LP4E
Split9	ATLM	LP4EE	KNN10	LP4EE	ATLM	LP4EE	RF	RF	ATLM	LP4E
Split10	ATLM	LP4EE	KNN10	LP4EE	ATLM	LP4EE	ATLM	CART	ATLM	LP4E
Split11	SVR	SVR	KNN10	LP4EE	RF	LP4EE	ATLM	RF	ATLM	LP4E
Split12	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	RF	RF	ATLM	LP4E
Split13	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	ATLM	KNN10	ATLM	LP4E
Split14	ATLM	LP4EE	KNN10	LP4EE	ATLM	LP4EE	RF	RF	ATLM	LP4E
Split15	ATLM	LP4EE	RF	LP4EE	ATLM	LP4EE	RF	RF	ATLM	LP4E
Split16	ATLM	LP4EE	RF	LP4EE	KNN10	LP4EE	RF	RF	ATLM	LP4E
Split17	ATLM	LP4EE	KNN10	LP4EE	RF	RF	RF	RF	KNN10	LP4E
Split18	ATLM	LP4EE	KNN10	LP4EE	RF	LP4EE	RF	RF	ATLM	LP4E
Split19	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	RF	RF	ATLM	LP4E
Split20	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	ATLM	RF	ATLM	LP4E
Split21	ATLM	LP4EE	RF	LP4EE	ATLM	LP4EE	ATLM	SVR	ATLM	LP4E
Split22	ATLM	LP4EE	KNN10	LP4EE	ATLM	LP4EE	RF	RF	ATLM	LP4E
Split23	ATLM	LP4EE	KNN10	LP4EE	KNN10	KNN10	RF	RF	ATLM	LP4E
Split24	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	RF	RF	ATLM	LP4E
Split25	ATLM	LP4EE	RF	LP4EE	ATLM	LP4EE	CART	CART	ATLM	LP4E
Split26	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	ATLM	RF	ATLM	LP4E
Split27	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	RF	RF	ATLM	LP4E
Split28	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	RF	RF	ATLM	LP4E
Split29	ATLM	LP4EE	KNN10	LP4EE	RF	LP4EE	RF	RF	ATLM	LP4E
Split30	ATLM	LP4EE	KNN10	LP4EE	KNN10	LP4EE	ATLM	SVR	ATLM	LP4E

FURTHER RESULTS IN THE PAPER…

Estimation accuracy

LP4EE is more accurate than ATLM and often also standard methods

Robustness to data splits

LP4EE is more stable than ATLM when using different data splits

Robustness to cross-validation method

LP4EE and ATLM are both quite robust (only few statistically sign. difference observed for leave-one-out vs. 3-fold cross-validation)

WHAT'S NEXT?

USE LP4EE!

To benchmark novel prediction models

As prediction model itself when the aim is to obtain a lower bound on the results, which is stable and robust

EXTEND LP4EE!

Is it effective for other prediction tasks?

Can it be further enhanced?

LP4EE: OPEN SOURCE REFERENCE IMPLEMENTATION IN R

Data+Results

GitHub Repo

@f_sarro

LINEAR PROGRAMMING AS A BASELINE FOR EFFORT ESTIMATION

ACM TOSEM 2018

by Sarro and Petrozziello

TAKE AWAY

Benchmark novel effort estimation models against LP4EE

Data+Results GitHub Repo

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