Machine Learning Techniques for Software Maintainability Prediction: Accuracy Analysis

Sara Elmidaoui[1], Laila Cheikhi [1], Ali Idri[1], and Alain Abran[2]

[1] *SPM Team, ENSIAS, Mohammed V University in Rabat, Morocco*

[2]*Department of Software Engineering & Information Technology, École de Technologie Supérieure, Montréal, Canada*

E-mail: sara.elmidaoui@um5s.net.ma; laila.cheikhi@um5.ac.ma; ali.idri@um5.ac.ma; alain.abran@etsmtl.ca

Appendix

Table A-1: QA score of selected primary studies

ID	Author	Ref.	QA1	QA2	QA3	QA4	QA5	QA6	QA7	QA8	Score
S1	S. Muthanna et al.	[19]	1	1	0	1	0	0	0	1	4
S2	M.M.T Thwin et al	[68]	1	1	1	0.5	1	1	1	1	7.5
S3	M. Genero et al.	[20]	1	1	0	0.5	0	1	0.5	1	5
S4	M. Kiewkayna et al.	[42]	1	1	1	0.5	0	0	0.5	1	5
S5	G.A.D. Lucca et al.	[67]	1	1	0	0.5	0	0.5	0	1	4
S6	C.V. Koten et al.	[45]	1	1	1	1	1	1	1	1	8
S7	J.H. Hayes et al.	[46]	1	1	0	0.5	0	0.5	0	1	4
S8	S.C. Misra	[34]	1	1	0	0.5	0	1	0	1	4.5
S9	Y. Zhou et al.	[44]	1	1	1	1	1	1	1	1	8
S10	X. Jin et al.	[35]	1	1	1	1	1	1	1	1	8
S11	S.S. Dahiya et al.	[37]	1	1	0	0.5	0	0.5	0	1	4
S12	M. Genero et al.	[47]	1	1	0	1	0	0.5	0	1	4.5
S13	K. Shibata et al.	[66]	1	1	0	0.5	0	0.5	0	1	4
S14	K.K.Aggarwal et al.	[69]	0.5	0.5	0	0.5	1	1	0	0.5	4
S15	Y. Thian et al.	[70]	1	1	1	1	1	1	1	1	8
S16	Y. Zhou et al.	[48]	1	1	0	1	1	1	0	1	6
S17	YU, Haiquan et al.	[95]	1	1	0	1	0	0	0	1	4
S18	A. Sharma et al.	[21]	1	1	0	0.5	0	0.5	0	1	4
S19	W. Li-jin et al.	[26]	1	1	1	1	1	1	1	1	8
S20	H. Mittal et al.	[36]	1	1	0	0.5	0	1	0	1	4.5
S21	M. O. Elish et al.	[86]	1	1	1	1	1	1	1	1	8
S22	S. Rizvi et al.	[49]	1	1	0	0.5	0	1	0.5	1	5
S23	A.Kaur et al.	[27]	1	1	1	1	0	1	1	1	7
S24	C. Jin et al.	[82]	1	0.5	0	1	0	1	0	1	4.5
S25	L. CAI et al.	[87]	1	1	0	0.5	0	0.5	0	1	4
S26	S. O. Olatunji et al.	[71]	1	1	1	1	1	1	1	1	8
S27	P. Dhankhar et al.	[88]	1	1	0	0.5	0	0.5	0	1	4
S28	S.K. Dubey et al.	[89]	1	1	0	0.5	0	0.5	0	1	4

ID	Author	Ref.	QA1	QA2	QA3	QA4	QA5	QA6	QA7	QA8	Score
S29	S. K. Dubey et al.	[33]	1	1	1	1	1	1	1	1	8
S30	N. Tagoug et al.	[50]	1	1	0	1	0	0.5	0	1	4.5
S31	S. Sharawat et al.	[22]	1	1	0	0.5	0	0.5	0	1	4
S32	H.A. Al-Jamimi et al.	[23]	1	1	0	1	0	1	0	1	5
S33	R. Malhotra et al.	[72]	1	1	1	1	0	1	1	1	7
S34	T. Bakota et al.	[64]	1	1	0	1	0	1	0	1	5
S35	Y. Dash et al.	[73]	1	1	1	1	0	1	1	1	7
S36	P. Hegedűs et al.	[51]	1	1	1	1	1	1	1	1	8
S37	D. Chandra	[83]	1	1	0	1	0	1	0	1	5
S38	H. Aljamaan et al.	[74]	1	1	1	1	1	1	1	1	8
S39	P. Hegedűs et al.	[65]	1	1	0	1	0	1	0	1	5
S40	X.L. Hao et al.	[90]	1	1	0	1	0	0	0	1	4
S41	F. Ye et al.	[75]	1	1	1	0.5	1	1	1	1	7.5
S42	M. A. Ahmed et al.	[76]	1	1	1	1	0	1	1	1	7
S43	S.O. Olatunji et al.	[77]	1	1	1	1	1	1	1	1	8
S44	A. Kaur et al.	[24]	1	1	1	1	1	1	1	1	8
S45	A. Mehra et al.	[96]	1	1	1	0.5	0	1	1	1	6.5
S46	J. Al Dallal.	[52]	1	1	0	1	1	1	0	1	6
S47	R. Malhotra et al.	[78]	1	1	1	1	0	1	1	1	7
S48	A. Kaur et al.	[28]	1	1	1	1	0	1	1	1	7
S49	A. Kaur et al.	[25]	1	1	1	1	0	1	1	1	7
S50	A. Pratap et al.	[38]	1	1	0	1	0	0.5	0	0.5	4
S51	R. Kumar et al.	[53]	1	1	1	0.5	0	1	0	1	5.5
S52	R. Malhotra et al.	[54]	1	1	1	1	0	1	1	1	7
S53	S. Misra et al.	[55]	1	1	0	0.5	0.5	0.5	0.5	0.5	4.5
S54	M.O. Elish et al.	[56]	1	1	1	1	1	1	1	1	8
S55	L. Kumar et al.	[79]	1	1	1	1	0	1	1	1	7
S56	S.O. Olatunji et al.	[91]	1	1	1	1	0	1	1	1	7
S57	A.K. Soni et al.	[80]	1	1	1	1	1	1	1	1	8
S58	L. Kumar et al.	[31]	1	1	1	1	1	1	1	1	8
S59	A. Jain et al.	[81]	1	1	1	1	0	1	1	1	7
S60	A. Chug et al.	[32]	1	1	1	1	1	1	1	1	8
S61	L. Kumar et al.	[84]	1	1	1	1	0	1	1	1	7
S62	S. Tarwani et al.	[57]	1	1	1	1	1	1	1	1	8
S63	S. Almugrin et al.	[58]	1	1	0	1	0	0.5	0	1	4.5
S64	S. Tarwani et al.	[39]	1	1	0	0.5	0	0.5	0	1	4
S65	L. Kumar et al.	[59]	1	1	1	1	1	1	1	1	8
S66	K. Gupta et al.	[60]	1	1	1	1	0	1	1	1	7
S67	S. Kundu et al.	[92]	1	1	0	1	0	0	0	1	4
S68	B.R. Reddy et al.	[61]	1	1	1	1	1	1	1	1	8
S69	L. Kumar et al.	[93]	1	1	1	1	1	1	1	1	8
S70	L. Kumar et al.	[29]	1	1	1	1	0	1	1	1	7
S71	L. Kumar et al.	[62]	1	1	1	1	0	1	1	1	7

ID	Author	Ref.	QA1	QA2	QA3	QA4	QA5	QA6	QA7	QA8	Score
S72	L. Kumar et al.	[85]	1	1	1	1	1	1	1	1	8
S73	R. Malhotra et al.	[63]	1	1	1	1	1	1	1	1	8
S74	G. Szoke et al.	[40]	1	1	0	0.5	0.5	0	0	1	4
S75	Y. Gokul et al.	[94]	1	1	0	0.5	0.5	0	0	1	4
S76	P. Hegedűs et al.	[41]	1	1	0	1	0	0	0	1	4
S77	L. Kumar et al.	[30]	1	1	1	1	1	1	1	1	8

Table A-2. Techniques Acronyms

Acronyms	Technique
AdaBoost	Adaptive Boosting
AFGA	Adaptive FLANN-genetic
ANFIS	Adaptive Neuro-Fuzzy Inference Systems
ANN	Artificial Neural Network
AODE	Aggregating One-Dependence Estimators
AR	Additive Regression
AVG	AVeraGe-based ensemble
BE	Backward Elimination
BN	Bayesian Network
BPNN	Back Propagation Neural Network
BTE	Best-in-Training-based Ensemble
CBR	CBR
CR	Conjunctive Rule
DFT	Decision Tree Forest
DS	Decision Stump
DT	Decision Tree
DTable	Decision Table
EA	Evolutionary Algorithms
ELM	Extreme Learning Machines
ELM-LIN	ELM with Linear
ELM-PLY	ELM with Polynomial
ELM-RBF	ELM with radial basis function kernels
ES	Ensemble Selection
FCSA	FLANN-clonal selection algorithm
FET	Fuzzy Entropy Theory
FF3LBPN	Feed Forward 3-Layer Back Propagation Network
FFNN	Feed Forward Neural Network
FGA	Functional Link Artificial Neural Network (FLAAN) with Genetic Algorithm
FIS	Fuzzy Inference Systems
FIT	Fuzzy Integral Theory
FL	Fuzzy Logic
FPSO	FLANN-Particle Swarm Optimization
FSC	Fuzzy Subtractive Clustering
GA	Genetic Algorithm
GdA	Greedy Algorithm
GEP	Genetic Expression Programming
GGAL	GRNN with Genetic Adaptive Learning
GMDH	Group Method Of Data Handling
GMM	Gaussian Mixture Model
GPR	Gaussian Process Regression
GRNN	General Regression Neural Network
IBK or KNN	K Nearest Neighbor
IR	Isotonic Regression
JERN	Jordan Elman Recurrent Network
K*	Kstar
KMC	K-means Clustering Algorithm

Acronyms	Technique
KN	Kohonen Network
Lasso	Least Absolute Shrinkage and Selection Operator
LgR	Logistic Regression
LMSR	Least Median Of Squares Regression
LR	Linear Regression
LSSVM-LIN	Least Square Support Vector Machine (LSSVM) with LINear kernel
LSSVM-PLY	LSSVM with PoLYnomial kernel
LSSVM-RBF	LSSVM with Radial Basis Function kernel
LSSVM-SIG	LSSVM with SIGmoid kernel
LWL	Locally Weighted Learning
M5P	M5 For Inducing Trees of Regression Models
M5R	M5 rules
MARS	Multiple Adaptive Regression Splines
MFL	Mamdani-based Fuzzy Logic
MFPSO	modified-FLANN particle swarm optimization
MLP	Multilayer Perceptron
MLR	Multiple Linear Regression
MV	Majority-Voting ensemble
NB	Naïve-Bayes
NDTF	Nonlinear ensemble Decision Tree Forest
neuro-GA	Neuro-Genetic Algorithm
NGD	ANN with Normally Gradient Descent
NGDA	ANN with Gradient Descent With Adaptive Learning Rate
NGDM	ANN with Gradient Descent With Momentum
NL	Non-Linear ensemble
NLM	ANN with Levenberg Marquardt
NNge	Nearest-Neighbor-Like Algorithm that uses Non-Nested Generalized Exemplars
NNM	ANN with Quasi-Newton Method
PaceR	Pace Regression
PD	Probability Density Function
PNN	Probabilistic Neural Network
PPR	Projection Pursuit Regression
PR	Polynomial Regression
RBF	Radial Basis Function Network
RegByDisc	Regression By Discretization
REPTree	Reduced Error Pruned Tree
RF	Random Forest
RT	Regression Tree
SBLLM	Sensitivity Based Linear Learning Method
SMO	Sequential Minimal Optimization
SS	Stepwise Selection
SVM	Support Vector Machine
SVM-LIN	SVM with LINear kernel
SVM-PLY	SVM with PoLYnomial kernel
SVM-RBF	SVM with Radial Basis Function kernel
SVM-SIG	SVM with SIGmoid kernel
SVR	Support Vector Regression
T2FLS	Type-2 Fuzzy Logic System
WNN	Ward Neural Network
WT	WeighTed-based ensemble
XMC	X-means Clustering Algorithm

Table A-3. Techniques and accuracy criteria cross validation of selected studies

ID	Year	Techniques	Accuracy criteria	Cross validation
S1	2000	PR	R-square	-
S2	2003	GRNN, WNN	R-square, R, MSE, MAE, MinAE, MaxAE	CV
S3	2003	MLR	MMRE, qMRE, Pred 30)	-
S4	2004	MD, WSL, WPL	Accuracy	-
S5	2004	WF	-	-
S6	2005	BN, RT, BE, SS	MaxMRE, MMRE, Pred(25), Pred(30), sum Ab.Res, Med. Ab.Res, Std. Ab.Res	10-FCV
S7	2005	MLR	R-square	-
S8	2005	MLR	R-square, R, adjusted R-square, Std.EE	
S9	2006	MARS, MLR, ANN, RT, SVR	MaxMRE, MMRE, Pred(25), Pred(30), sum ARE, Med. ARE, Std. ARE	LOOCV
S10	2006	GMM, SVM-RBF, DT	WAP, Recall	10-FCV
S11	2007	FL	-	-
S12	2007	MLR	-	-
S13	2007	SM	PLL, PSE	-
S14	2008	ANN	MARE, R, MRE	10-FCV
S15	2008	AODE, SVM-LIN, NB, BN, RF, KNN, C4.5, OneR, RBF	WAP, WARec	10-FCV
S16	2008	MLR	R-square, MARE, MMRE.	LOOCV
S17	2009	CBR	-	-
S18	2009	FL	-	-
S19	2009	PPR, ANN, MARS	RMSE	LOOCV
S20	2009	FL	-	-
S21	2009	TreeNet	MMRE, Pred(25), Pred(30)	LOOCV
S22	2010	MLR	PC	-
S23	2010	FFNN, FIS, ANFIS, GRNN, RBF	MARE, MRE, R	-
S24	2010	SVM	MARE, MRE, R	-
S25	2010	FET	-	-
S26	2010	ELM	MaxMRE, MMRE, Pred(25), Pred(30), Sum Ab.Res, Med. Ab.Res, Std. Ab.Res	CV
S27	2011	FL	-	-
S28	2012	FL	-	-
S29	2012	MLP	R-square, R, MAE, minAE, maxAE	CV
S30	2012	LR	-	-
S31	2012	ANN	-	-
S32	2012	MFL	RMSE, NRMSE, MMRE	
S33	2012	GMDH, GA, PNN	MaxMRE, MMRE, MARE, Pred(25), Pred(30), Pred(75)	
S34	2012	PD	MSE, PC	
S35	2012	MLP	R, MAE	
S36	2012	LR, ANN, DT	PC, MAE	10-FCV
S37	2012	SVM-RBF	MARE, MRE, R	
S38	2013	MLP, RBF, SVM, M5P, Ensemble	MMRE, Std. MRE, Pred(30)	10-FCV
S39	2013	PD	R	
S40	2013	FIT	-	
S41	2013	DT, BPNN, SVM, Bagging	TPR, FPR, Precision, Recall, F1 score, AUC	CV
S42	2013	MFL, ANFIS, PNN, RBF, SVM	NRMSE, MMRE, Pred(25), Pred(30).	

ID	Year	Techniques	Accuracy criteria	Cross validation
S43	2013	SBLLM, ELM	MaxMRE, MMRE, Pred(25), Pred(30), Sum Ab.Res., Med. Ab.Res., Std. Ab.Res.	CV
S44	2013	MLR, LMSR, PaceR, PPR, IR, RegByDisc, GPR, MLP, RBF, AR, GRNN, GMDH, SVR, FSC, DS, ANFIS, K*, M5P, LWL, Bagging, KNN, REPTree, RF, ES, CR, DTable, M5R	MaxMRE, MMRE, Pred(25), Pred(30), Sum ARE, Med. ARE, Std. ARE, RMSE	LOOCV
S45	2013	KMC, XMC	Qout, Nit, cut-off	
S46	2013	LgR	Precision, recall, IP, IR, MSE, R-square, ROC area, AUC.	10-FCV
S47	2014	GMDH, FF3LBPN, GRNN	MMRE, Pred(25), Pred(30), % under, % over	
S48	2014	SS, BE	R-square, R	
S49	2014	NB, BN, LgR, MLP, RF	recall, precision, ROC area	
S50	2014	FL	-	
S51	2014	MLR	Rs	
S52	2014	MLR, BPNN, KN, FFNN, GRNN	MaxMRE, MMRE, Pred(25)	
S53	2014	LR	Rs	
S54	2015	MLP, RBF, SVM, M5P, DT, LgR, KMC, GEP, MV, NL, Boosting, Bagging, AVG, WT, BTE	MMRE, Std. MRE, Pred(30), CCR, AUC	10-FCV, LOOCV
S55	2015	ANN, Neuro-GA	MMRE, MARE, MAE, RMSE, SEM	
S56	2015	T2FLS	MaxMRE, MMRE, Pred(25), Pred(30), Sum Ab.Res., Std. Ab.Res.	
S57	2015	Neuro-GA	MAE, MARE, RMSE, SEM, MMRE, e, é	5/10-FCV
S58	2016	FGA, AFGA, FPSO, MFPSO, FCSA	MAE, R, MMRE, e, é	5/10-FCV
S59	2016	GA, DTable, RBF, BN, SMO	MAE, RMSE	
S60	2016	LR, M5R, DT, SVM, K*, Bagging, JERN, BPNN, KN, PNN, GMDH, GRNN, GGAL	MAE, RMSE, Pred(25), Pred(75)	10-FCV
S61	2016	SVM-LIN, SVM-SIG, SVM-RBF	precision, recall, F-measure, specificity, accuracy, AUC	
S62	2016	GEP, DFT, SVM, LR, MLP, RBF	MAE, RMSE	10-FCV
S63	2016	MLR	R^2	
S64	2016	GdA	-	
S65	2017	LR, NB, ELM-LIN, ELM-PLY, ELM-RBF, SVM-LIN, SVM-RBF, SVM-SIG, BTE, MV	Accuracy, AUC	10-FCV
S66	2017	LR, Cubist, Lasso, Elastic Net, RF	MAE, RMSE, Accuracy	
S67	2017	FL	Performance index	
S68	2017	MLR, MLP, SVR, M5P	AOC, StdMRE, MMRE, Pred(30)	10-FCV
S69	2017	Neuro Fuzzy	MAE, MMRE, SEM	5-FCV
S70	2017	SVM-LIN, SVM-SIG, SVM-RBF	F-measure, accuracy	
S71	2017	MARS, MLR, SVM	Accuracy, Recall, Precision	
S72	2017	LSSVM-LIN, LSSVM-RBF, LSSVM-SIG	F-measure, Accuracy	20-FCV
S73	2017	LgR, RF, Bagging, AdaBoost, MLP, BN, NB, LogitBoost, J48, NNge	Sensitivity, Specificity, ROC, cutoff	10-FCV, Inter-Project
S74	2017	Probability approach	-	
S75	2017	MFL	-	

ID	Year	Techniques	Accuracy criteria	Cross validation
S76	2018	SM	Rs	
S77	2018	LR, PR, LgR, DT, SVM-LIN, SVM-PLY, SVM-RBF, ELM-LIN, ELM-PLY, ELM-RBF, LSSVM-LIN, LSSVM-PLY, LSSVM-RBF, NGD, NGDM, NGDA, NNM, MVE, NDTF, BTE	Accuracy, F-measure	5-FCV

Accuracy criteria acronyms: standard error of the estimate (Std. EE)., weighted average precision (WAP), precision, adjusted R-square, area under curve (AUC), standard error of the mean (SEM), correct classification rate (CCR), true error (e), estimate of true error (é), Pearson correlation (PC), Roc area, true positive rate (TPR), false positive rate (FPR), weighted average recall (WARec), inverse precision (IP), inverse recall (IR), F-measures (F1 score), prediction logarithmic likelihood (PLL), prediction square error (PSE), accuracy, percentage of underestimate (% under), percentage of overestimate (% over) and Spearman's coefficient of correlation (Rs), quality of outputs (Qout), number of iterations (Nit) and cut-off factors (cut-off), mean square error(MSE).

Table A-4. Estimation accuracy values of SPMP

ID study	MMRE (%)	Pred(25) (%)	Pred(30) (%)	Dataset	ID study	MMRE (%)	Pred(25) (%)	Pred(30) (%)	Dataset
S6	97.20	44.60	46.90	UIMS	S44	195.00	13.00	15.00	UIMS
S6	45.20	39.10	43.00	QUES	S44	59.00	37.00	44.00	QUES
S6	153.80	20.00	20.80	UIMS	S44	410.00	21.00	21.00	UIMS
S6	49.30	35.20	38.30	QUES	S44	95.00	28.00	37.00	QUES
S9	495.00	10.00	10.00	UIMS	S44	608.00	26.00	36.00	UIMS
S9	58.00	41.00	45.00	QUES	S44	57.00	51.00	59.00	QUES
S9	195.00	15.00	15.00	UIMS	S44	65.00	33.00	38.00	UIMS
S9	59.00	37.00	45.00	QUES	S44	37.00	51.00	62.00	QUES
S9	168.00	31.00	36.00	UIMS	S44	65.00	33.00	41.00	UIMS
S9	43.00	34.00	46.00	QUES	S44	37.00	54.00	61.00	QUES
S21	42.00	58.00	65.00	QUES	S44	129.00	28.00	33.00	UIMS
S21	157.00	31.00	41.00	UIMS	S44	54.00	32.00	38.00	QUES
S26	96.80	39.20	45.00	UIMS	S44	140.00	18.00	23.00	UIMS
S26	35.02	36.80	38.00	QUES	S44	38.00	45.00	50.00	QUES
S32	30.00 [a]	-	-	QUES	S44	259.00	26.00	26.00	UIMS
S32	81.00 [a]	-	-	UIMS	S44	82.00	24.00	27.00	QUES
S33	21.00	69.00	72.20	QUES, UIMS	S44	495.00	10.00	10.00	UIMS
S33	23.00	68.00	75.00	QUES, UIMS	S44	58.00	41.00	45.00	QUES
S33	22.00	66.00	72.20	QUES, UIMS	S44	131.00	23.00	28.00	UIMS
S38	139.00	-	23.33	UIMS	S44	35.00	39.00	46.00	QUES
S38	71.00	-	40.00	QUES	S44	102.00	38.00	38.00	UIMS
S38	323.00	-	15.00	UIMS	S44	27.00	62.00	65.00	QUES
S38	96.00	-	36.66	QUES	S44	414.00	18.00	21.00	UIMS
S38	167.00	-	23.33	UIMS	S44	69.00	34.00	38.00	QUES
S38	54.00	-	51.66	QUES	S44	56.00	36.00	41.00	UIMS
S38	164.00	-	20.00	UIMS	S44	27.00	56.00	66.00	QUES
S38	44.00	-	56.66	QUES	S44	95.00	15.00	21.00	UIMS

S42	22.00 [a]	52.00 [a]	62.00 [a]	QUES	S44	63.00	41.00	45.00	QUES
S42	52.00 [a]	30.00 [a]	35.00 [a]	UIMS	S44	41.00	52.00	55.00	QUES
S42	41.00 [a]	34.00 [a]	40.00 [a]	QUES, UIMS	S44	530.00	5.00	5.00	UIMS
S43	35.02	36.80	38.00	QUES	S47	54.76	44.00	47.00	FLM, EASY
S43	96.80	39.20	45.00	UIMS	S47	35.66	61.00	71.00	FLM, EASY
S43	34.80	50.00	56.00	QUES	S47	45.78	51.00	59.00	FLM, EASY
S43	196.60	17.90	25.00	UIMS	S52	37.00 [a]	77.00 [a]	-	EASY
S44	142.00	26.00	28.00	UIMS	S52	46.00 [a]	63.00 [a]	-	EASY
S44	89.00	24.00	31.00	QUES	S52	36.00 [a]	74.00 [a]	-	EASY
S44	184.00	26.00	28.00	UIMS	S52	42.00 [a]	69.00 [a]	-	EASY
S44	55.00	32.00	38.00	QUES	S52	47.00 [a]	69.00 [a]	-	FLM
S52	39.00 [a]	71.00 [a]	-	FLM	S60	-	49.00	-	Abdera
S52	41.00 [a]	76.00 [a]	-	FLM	S60	-	51.00	-	Abdera
S52	42.00 [a]	78.00 [a]	-	FLM	S60	-	52.00	-	Abdera
S52	41.00 [a]	77.00 [a]	-	SMS	S60	-	73.00	-	Abdera
S52	38.00 [a]	69.00 [a]	-	SMS	S60	-	72.00	-	Abdera
S52	39.00 [a]	71.00 [a]	-	SMS	S60	-	63.00	-	Drumkit
S52	40.00 [a]	69.00 [a]	-	SMS	S60	-	70.00	-	Drumkit
S52	29.00 [a]	69.00 [a]	-	IMS	S60	-	65.00	-	Drumkit
S52	32.00 [a]	70.00 [a]	-	IMS	S60	-	68.00	-	Drumkit
S52	35.00 [a]	71.00 [a]	-	IMS	S60	-	68.00	-	Drumkit
S52	30.00 [a]	63.00 [a]	-	IMS	S60	-	62.00	-	Abdera
S52	40.00 [a]	74.00 [a]	-	ABP	S60	-	53.00	-	Abdera
S52	37.00 [a]	66.00 [a]	-	ABP	S60	-	65.00	-	Abdera
S52	29.00 [a]	67.00 [a]	-	ABP	S60	-	65.00	-	Abdera
S52	32.00 [a]	72.00 [a]	-	ABP	S60	-	57.00	-	Abdera
S54	139.00	-	23.33	UIMS	S60	-	59.00	-	Abdera
S54	71.00	-	40.00	QUES	S60	-	59.00	-	Ivy
S54	323.00	-	15.00	UIMS	S60	-	57.00	-	Ivy
S54	96.00	-	36.66	QUES	S60	-	52.00	-	Ivy

S54	167.00	-	23.33	UIMS	S60	-	58.00	-	Ivy
S54	54.00	-	51.66	QUES	S60	-	62.00	-	Drumkit
S54	164.00	-	20.00	UIMS	S60	-	67.00	-	Drumkit
S54	44.00	-	56.66	QUES	S60	-	51.00	-	Drumkit
S55	69.31	-	-	UIMS	S60	-	69.00	-	Drumkit
S55	43.84	-	-	QUES	S60	-	65.00	-	Drumkit
S55	53.32	-	-	UIMS	S60	-	72.00	-	Drumkit
S55	41.80	-	-	QUES	S60	-	49.00	-	OpenCV
S56	0.01	86.20	92.10	UIMS	S60	-	53.00	-	OpenCV
S57	31.55	-	-	UIMS	S60	-	47.00	-	OpenCV
S57	37.75	-	-	QUES	S60	-	55.00	-	OpenCV
S58	24.81 [a]	-	-	UIMS	S60	-	69.00	-	OpenCV
S58	38.89 [a]	-	-	QUES	S60	-	57.00	-	OpenCV
S58	25.24 [a]	-	-	UIMS	S60	-	63.00	-	OpenCV
S58	35.24 [a]	-	-	QUES	S60	-	61.00	-	OpenCV
S58	27.37 [a]	-	-	UIMS	S60	-	73.00	-	OpenCV
S58	36.50 [a]	-	-	QUES	S60	-	59.00	-	OpenCV
S58	25.09 [a]	-	-	UIMS	S60	-	67.00	-	OpenCV
S58	36.71 [a]	-	-	QUES	S60	-	51.00	-	JEdit
S58	27.02 [a]	-	-	UIMS	S60	-	61.00	-	JEdit
S58	45.07 [a]	-	-	QUES	S60	-	42.00	-	JEdit
S60	-	57.00	-	JEdit	S68	49.85 [a]	-	60.71 [a]	Free mind
S60	-	61.00	-	JEdit	S68	57.85 [a]	-	52.50 [a]	Games
S60	-	49.00	-	JEdit	S68	37.59 [a]	-	60..98 [a]	Gantt project
S60	-	58.00	-	JEdit	S68	21.24 [a]	-	84.62 [a]	Geoxygene
S60	-	59.00	-	JEdit	S68	20.46 [a]	-	84.60 [a]	Ivy
S60	-	73.00	-	JEdit	S68	78.56 [a]	-	53.85 [a]	Jabref
S60	-	52.00	-	JUnit	S68	377.81 [a]	-	60.00 [a]	Jajuk
S60	-	61.00	-	JUnit	S68	120.21 [a]	-	48.89 [a]	Jasper reports
S60	-	68.00	-	JUnit	S68	155.80 [a]	-	33.33 [a]	Javaml

S60	-	62.00	-	JUnit	S68	56.00 [a]	-	56.52 [a]	Jfree ant
S60	-	62.00	-	Ivy	S68	26.83 [a]	-	72.41 [a]	Jfree chart
S60	-	73.00	-	Ivy	S68	47.94 [a]	-	54.55 [a]	Jgap
S60	-	48.00	-	Ivy	S68	50.42 [a]	-	53.19 [a]	Jmt
S60	-	64.00	-	Ivy	S68	54.49 [a]	-	54.55 [a]	Jnetpcap
S60	-	78.00	-	Ivy	S68	24.84 [a]	-	79.60 [a]	Lucene
S60	-	68.00	-	Ivy	S68	33.44 [a]	-	70.59 [a]	Mallet
S60	-	75.00	-	Ivy	S68	38.57 [a]	-	60.00 [a]	Pandora
S60	-	65.00	-	Log4j	S68	35.05 [a]	-	61.70 [a]	POI
S60	-	68.00	-	Log4j	S68	28.33 [a]	-	64.71 [a]	Sglj
S60	-	73.00	-	Log4j	S68	21.52 [a]	-	65.52 [a]	Tree view
S60	-	72.00	-	Log4j	S68	37.21 [a]	-	60.87 [a]	Ujac
S60	-	74.00	-	Log4j	S68	00.00 [a]	-	100.00 [a]	Workzen
S60	-	77.00	-	Log4j	S68	36.66 [a]	-	66.70 [a]	Xalan
S60	-	73.00	-	Log4j	S68	25.23 [a]	-	83.33 [a]	Art of illusion
S60	-	73.00	-	Log4j	S68	14.26 [a]	-	93.10 [a]	Camel
S60	-	79.00	-	Log4j	S68	20.45 [a]	-	82.97 [a]	Eclipse
S60	-	71.00	-	Log4j	S68	30.15 [a]	-	75.00 [a]	Free mind
S60	-	69.00	-	Log4j	S68	55.85 [a]	-	40.00 [a]	Games
S60	-	75.00	-	JEdit	S68	31.65 [a]	-	68.29 [a]	Gantt project
S60	-	70.00	-	JEdit	S68	17.24 [a]	-	88.46 [a]	Geoxygene
S60	-	57.00	-	JUnit	S68	11.73 [a]	-	96.15 [a]	Ivy
S60	-	63.00	-	JUnit	S68	72.61 [a]	-	61.54 [a]	Jabref
S60	-	49.00	-	JUnit	S68	366.07 [a]	-	68.00 [a]	Jajuk
S60	-	61.00	-	JUnit	S68	175.01 [a]	-	42.22 [a]	Jasper reports
S60	-	52.00	-	JUnit	S68	97.99 [a]	-	75.00 [a]	Javaml
S60	-	60.00	-	JUnit	S68	60.99 [a]	-	56.52 [a]	Jfree ant
S60	-	74.00	-	JUnit	S68	28.93 [a]	-	65.52 [a]	Jfree chart
S68	30.85 [a]	-	61.11 [a]	Art of illusion	S68	48.32 [a]	-	72.73 [a]	Jgap
S68	19.75 [a]	-	79.31 [a]	Camel	S68	47.08 [a]	-	72.34 [a]	Jmt

S68	46.53 [a]	-	63.75 [a]	Eclipse	S68	60.36 [a]	-	72.73 [a]	Jnetpcap
S68	09.15 [a]	-	87.76 [a]	Lucene	S68	176.83 [a]	-	53.33 [a]	Jasper reports
S68	31.58 [a]	-	76.47 [a]	Mallet	S68	154.80 [a]	-	25.00 [a]	Javaml
S68	29.25 [a]	-	66.67 [a]	Pandora	S68	55.38 [a]	-	65.22 [a]	Jfree ant
S68	41.32 [a]	-	73.33 [a]	POI	S68	29.39 [a]	-	65.52 [a]	Jfree chart
S68	35.07 [a]	-	64.71 [a]	Sglj	S68	52.90 [a]	-	72.73 [a]	Jgap
S68	14.88 [a]	-	75.86 [a]	Tree view	S68	48.30 [a]	-	65.96 [a]	Jmt
S68	42.76 [a]	-	65.22 [a]	Ujac	S68	86.94 [a]	-	54.55 [a]	Jnetpcap
S68	00.02 [a]	-	100.00 [a]	Workzen	S68	14.49 [a]	-	89.80 [a]	Lucene
S68	27.87 [a]	-	75.00 [a]	Xalan	S68	36.13 [a]	-	78.43 [a]	Mallet
S68	29.53 [a]	-	72.22 [a]	Art of illusion	S68	31.32 [a]	-	73.33 [a]	Pandora
S68	20.96 [a]	-	75.86 [a]	Camel	S68	43.84 [a]	-	61.67 [a]	POI
S68	21.97 [a]	-	80.57 [a]	Eclipse	S68	40.67 [a]	-	64.71 [a]	Sglj
S68	60.83 [a]	-	78.57 [a]	Free mind	S68	14.57 [a]	-	75.86 [a]	Tree view
S68	59.56 [a]	-	45.00 [a]	Games	S68	38.46 [a]	-	73.91 [a]	Ujac
S68	27.83 [a]	-	73.17 [a]	Gantt project	S68	10.47 [a]	-	100.00 [a]	Workzen
S68	19.74 [a]	-	84.62 [a]	Geoxygene	S68	25.95 [a]	-	83.33 [a]	Xalan
S68	14.16 [a]	-	88.46 [a]	Ivy	S69	28.26	-	-	UIMS
S68	76.24 [a]	-	57.69 [a]	Jabref	S69	33.75	-	-	QUES
S68	350.72 [a]	-	60.00 [a]	Jajuk					

[a] accuracy value under best configuration.

Table A-5. Accuracy values of SPMP ML techniques

ID	MMRE (%)	Pred(25) (%)	Pred(30) (%)	Dataset	ID	MMRE (%)	Pred(25) (%)	Pred(30) (%)	Dataset
ANN technique									
S9	195.00	15.00	15.00	UIMS	S52	40.00 [a]	69.00 [a]	-	SMS
S9	59.00	37.00	45.00	QUES	S52	41.00 [a]	77.00 [a]	-	SMS
S26	96.8	39.00	45.00	UIMS	S52	38.00 [a]	69.00 [a]	-	SMS
S26	35.02	36.00	38.00	QUES	S52	29.00 [a]	69.00 [a]	-	IMS
S33	23.00	68.00	75.00	QUES, UIMS	S52	32.00 [a]	70.00 [a]	-	IMS
S33	21.00	69.00	72.20	QUES,UIMS	S52	35.00 [a]	71.00 [a]	-	IMS
S38	139.00	-	23.33	UIMS	S52	30.00 [a]	63.00 [a]	-	IMS
S38	71.00	-	40.00	QUES	S52	40.00 [a]	74.00 [a]	-	ABP
S38	323.00	-	15.00	UIMS	S52	37.00 [a]	66.00 [a]	-	ABP
S38	96.00	-	36.66	QUES	S52	29.00 [a]	67.00 [a]	-	ABP
S43	35.02	36.80	38.00	QUES	S52	32.00 [a]	72.00 [a]	-	ABP
S43	96.8	39.20	45.00	UIMS	S54	139.00	-	23.33	UIMS
S43	34.8	50.00	56.00	QUES	S54	71.00	-	40.00	QUES
S43	196.6	17.90	25.00	UIMS	S54	323.00	-	15.00	UIMS
S44	142.00	26.00	28.00	UIMS	S54	96.00	-	36.66	QUES
S44	41.00	52.00	55.00	QUES	S55	69.31	-	-	UIMS
S44	195.00	13.00	15.00	UIMS	S55	43.84	-	-	QUES
S44	59.00	37.00	44.00	QUES	S55	53.32	-	-	UIMS
S44	410.00	21.00	21.00	UIMS	S55	41.80	-	-	QUES
S44	95.00	28.00	37.00	QUES	S57	37.75	-	-	QUES
S44	608.00	26.00	36.00	UIMS	S57	31.55	-	-	UIMS
S44	57.00	51.00	59.00	QUES	S58	24.81 [a]	-	-	UIMS
S47	54.76	61.00	71.00	FLM, EASY	S58	38.89 [a]	-	-	QUES
S47	35.66	51.00	59.00	FLM, EASY	S58	25.24 [a]	-	-	UIMS
S47	45.78	44.00	47.00	FLM, EASY	S58	35.24 [a]	-	-	QUES
S52	37.00 [a]	77.00 [a]	-	EASY	S58	27.37 [a]	-	-	UIMS

S52	46.00 [a]	63.00 [a]	-	EASY	S58	36.50 [a]	-	-	QUES
S52	36.00 [a]	74.00 [a]	-	EASY	S58	25.09 [a]	-	-	UIMS
S52	42.00 [a]	69.00 [a]	-	EASY	S58	36.71 [a]	-	-	QUES
S52	47.00 [a]	69.00 [a]	-	FLM	S58	27.02 [a]	-	-	UIMS
S52	39.00 [a]	71.00 [a]	-	FLM	S58	45.07 [a]	-	-	QUES
S52	41.00 [a]	76.00 [a]	-	FLM	S60	-	58.00	-	JEdit
S52	42.00 [a]	78.00 [a]	-	FLM	S60	-	59.00	-	JEdit
S52	39.00 [a]	71.00 [a]	-	SMS	S60	-	73.00	-	JEdit
S60	-	70.00	-	JEdit	S60	-	73.00	-	OpenCV
S60	-	75.00	-	JEdit	S60	-	68.00	-	JUnit
S60	-	61.00	-	JEdit	S60	-	69.00	-	OpenCV
S60	-	49.00	-	JEdit	S60	-	57.00	-	OpenCV
S60	-	60.00	-	JUnit	S60	-	59.00	-	OpenCV
S60	-	74.00	-	JUnit	S60	-	67.00	-	OpenCV
S60	-	52.00	-	JUnit	S68	30.85 [a]	-	61.11 [a]	Art of illusion
S60	-	61.00	-	JUnit	S68	19.75 [a]	-	79.31 [a]	Camel
S60	-	62.00	-	JUnit	S68	46.53 [a]	-	63.75 [a]	Eclipse
S60	-	52.00	-	JUnit	S68	49.85 [a]	-	60.71 [a]	Free mind
S60	-	48.00	-	Ivy	S68	57.85 [a]	-	52.50 [a]	Games
S60	-	64.00	-	Ivy	S68	37.59 [a]	-	60..98 [a]	Gantt project
S60	-	78.00	-	Ivy	S68	21.24 [a]	-	84.62 [a]	Geoxygene
S60	-	68.00	-	Ivy	S68	20.46 [a]	-	84.60 [a]	Ivy
S60	-	75.00	-	Ivy	S68	78.56 [a]	-	53.85 [a]	Jabref
S60	-	62.00	-	Ivy	S68	377.81 [a]	-	60.00 [a]	Jajuk
S60	-	73.00	-	Ivy	S68	120.21 [a]	-	48.89 [a]	Jasper reports
S60	-	74.00	-	Log4j	S68	155.80 [a]	-	33.33 [a]	Javaml
S60	-	77.00	-	Log4j	S68	56.00 [a]	-	56.52 [a]	Jfree ant
S60	-	73.00	-	Log4j	S68	26.83 [a]	-	72.41 [a]	Jfree chart
S60	-	73.00	-	Log4j	S68	47.94 [a]	-	54.55 [a]	Jgap
S60	-	79.00	-	Log4j	S68	50.42 [a]	-	53.19 [a]	Jmt

S60	-	71.00	-	Log4j	S68	54.49 [a]	-	54.55 [a]	Jnetpcap
S60	-	69.00	-	Log4j	S68	24.84 [a]	-	79.60 [a]	Lucene
S60	-	72.00	-	Abdera	S68	33.44 [a]	-	70.59 [a]	Mallet
S60	-	62.00	-	Abdera	S68	38.57 [a]	-	60.00 [a]	Pandora
S60	-	53.00	-	Abdera	S68	35.05 [a]	-	61.70 [a]	POI
S60	-	65.00	-	Abdera	S68	28.33 [a]	-	64.71 [a]	Sglj
S60	-	65.00	-	Abdera	S68	21.52 [a]	-	65.52 [a]	Tree view
S60	-	59.00	-	Abdera	S68	37.21 [a]	-	60.87 [a]	Ujac
S60	-	73.00	-	Abdera	S68	00.00 [a]	-	100.00 [a]	Workzen
S60	-	67.00	-	Drumkit	S68	36.66 [a]	-	66.70 [a]	Xalan
S60	-	51.00	-	Drumkit					
S60	-	69.00	-	Drumkit					
S60	-	65.00	-	Drumkit					
S60	-	72.00	-	Drumkit					
S60	-	68.00	-	Drumkit					
S60	-	62.00	-	Drumkit					
S60	-	63.00	-	OpenCV					
S60	-	61.00	-	OpenCV					
DT technique									
S6	153.80	20.00	20.00	UIMS	S68	20.96 [a]	-	75.86 [a]	Camel
S6	49.30	35.00	38.00	QUES	S68	21.97 [a]	-	80.57 [a]	Eclipse
S9	495.00	10.00	10.00	UIMS	S68	60.83 [a]	-	78.57 [a]	Free mind
S9	58.00	41.00	45.00	QUES	S68	59.56 [a]	-	45.00 [a]	Games
S21	42.00	58.00	65.00	QUES	S68	27.83 [a]	-	73.17 [a]	Gantt project
S21	157.00	31.00	41.00	UIMS	S68	19.74 [a]	-	84.62 [a]	Geoxygene
S38	167.00	-	23.33	UIMS	S68	14.16 [a]	-	88.46 [a]	Ivy
S38	45.00	-	51.66	QUES	S68	76.24 [a]	-	57.69 [a]	Jabref
S44	38.00	45.00	50.00	QUES	S68	350.72 [a]	-	60.00 [a]	Jajuk
S44	129.00	28.00	33.00	UIMS	S68	176.83 [a]	-	53.33 [a]	Jasper reports
S44	54.00	32.00	38.00	QUES	S68	154.80 [a]	-	25.00 [a]	Javaml

S44	495.00	10.00	10.00	UIMS	S68	55.38 [a]	-	65.22 [a]	Jfree ant
S44	58.00	41.00	45.00	QUES	S68	29.39 [a]	-	65.52 [a]	Jfree chart
S44	140.00	18.00	23.00	UIMS	S68	52.90 [a]	-	72.73 [a]	Jgap
S44	259.00	26.00	26.00	UIMS	S68	48.30 [a]	-	65.96 [a]	Jmt
S44	82.00	24.00	27.00	QUES	S68	86.94 [a]	-	54.55 [a]	Jnetpcap
S54	167.00	-	23.33	UIMS	S68	14.49 [a]	-	89.80 [a]	Lucene
S54	54.00	-	51.66	QUES	S68	36.13 [a]	-	78.43 [a]	Mallet
S60	-	57.00	-	Ivy	S68	31.32 [a]	-	73.33 [a]	Pandora
S60	-	63.00	-	JUnit	S68	43.84 [a]	-	61.67 [a]	POI
S60	-	49.00	-	Abdera	S68	40.67 [a]	-	64.71 [a]	Sglj
S60	-	53.00	-	OpenCV	S68	14.57 [a]	-	75.86 [a]	Tree view
S60	-	70.00	-	Drumkit	S68	38.46 [a]	-	73.91 [a]	Ujac
S60	-	61.00	-	JEdit	S68	10.47 [a]	-	100.00 [a]	Workzen
S60	-	68.00	-	Log4j	S68	25.95 [a]	-	83.33 [a]	Xalan
S68	29.53 [a]		72.22 [a]	Art of illusion					
FNF technique									
S32	30.00 [a]	-	-	QUES	S44	37.00	51.00	62.00	QUES
S32	81.00 [a]	-	-	UIMS	S44	65.00	33.00	41.00	UIMS
S42	22.00 [a]	52.00 [a]	62.00 [a]	QUES	S44	37.00	54.00	61.00	QUES
S42	52.00 [a]	30.00 [a]	35.00 [a]	UIMS	S56	0.01	86.20	92.10	UIMS
S42	41.00 [a]	34.00 [a]	40.00 [a]	QUES, UIMS	S69	28.26	-	-	UIMS
S44	65.00	33.00	38.00	UIMS	S69	33.75	-	-	QUES
SVM/R technique									
S9	168.00	31.00	36.00	UIMS	S44	131.00	23.00	28.00	UIMS
S9	43.00	34.00	46.00	QUES	S54	164.00		20.00	UIMS
S38	164.00		20.00	UIMS	S54	44.00		56.66	QUES
S38	44.00		56.66	QUES	S60	-	51.00	-	Abdera
S44	35.00	39.00	46.00	QUES	S60	-	65.00	-	Drumkit
S60	-	47.00	-	OpenCV	S68	97.99 [a]	-	75.00 [a]	Javaml
S60	-	52.00	-	Ivy	S68	60.99 [a]	-	56.52 [a]	Jfree ant

S60	-	49.00	-	JUnit	S68	28.93 [a]	-	65.52 [a]	Jfree chart
S60	-	42.00	-	JEdit	S68	48.32 [a]	-	72.73 [a]	Jgap
S60	-	73.00	-	Log4j	S68	47.08 [a]	-	72.34 [a]	Jmt
S68	25.23 [a]	-	83.33 [a]	Art of illusion	S68	60.36 [a]	-	72.73 [a]	Jnetpcap
S68	14.26 [a]	-	93.10 [a]	Camel	S68	09.15 [a]	-	87.76 [a]	Lucene
S68	20.45 [a]	-	82.97 [a]	Eclipse	S68	31.58 [a]	-	76.47 [a]	Mallet
S68	30.15 [a]	-	75.00 [a]	Free mind	S68	29.25 [a]	-	66.67 [a]	Pandora
S68	55.85 [a]	-	40.00 [a]	Games	S68	41.32 [a]	-	73.33 [a]	POI
S68	31.65 [a]	-	68.29 [a]	Gantt project	S68	35.07 [a]	-	64.71 [a]	Sglj
S68	17.24 [a]	-	88.46 [a]	Geoxygene	S68	14.88 [a]	-	75.86 [a]	Tree view
S68	11.73 [a]	-	96.15 [a]	Ivy	S68	42.76 [a]	-	65.22 [a]	Ujac
S68	72.61 [a]	-	61.54 [a]	Jabref	S68	00.02 [a]	-	100.00 [a]	Workzen
S68	366.07 [a]	-	68.00 [a]	Jajuk	S68	27.87 [a]	-	75.00 [a]	Xalan
S68	175.01 [a]	-	42.22 [a]	Jasper reports					
CBR technique									
S44	102.00	38.00	38.00	UIMS	S60	-	68.00	-	Drumkit
S44	27.00	62.00	65.00	QUES	S60	-	57.00	-	JEdit
S44	414.00	18.00	21.00	UIMS	S60	-	55.00	-	OpenCV
S44	69.00	34.00	38.00	QUES	S60	-	52.00	-	Abdera
S44	56.00	36.00	41.00	UIMS	S60	-	58.00	-	Ivy
S44	27.00	56.00	66.00	QUES	S60	-	72.00	-	Log4j
S60	-	61.00	-	JUnit					
BN technique									
S6	97.20	44.00	46.00	UIMS	S6	45.20	39.00	43.00	QUES
EA technique									
S33	22.00	66.00	72.20	QUES,UIMS					
IRB technique									
S44	95.00	15.00	21.00	UIMS	S60	-	51.00	-	JEdit
S44	63.00	41.00	45.00	QUES	S60	-	57.00	-	Abdera
S44	184.00	26.00	28.00	UIMS	S60	-	49.00	-	OpenCV

S44	530.00	5.00	5.00	UIMS	S60	-	65.00	-	Log4j
S44	89.00	24.00	31.00	QUES	S60	-	63.00	-	Drumkit
S44	55.00	32.00	38.00	QUES	S60	-	59.00	-	Ivy
S60	-	57.00	-	JUnit					

[a]: accuracy value under best configuration

Table A-6. Comparison of MMRE between ML techniques and RA techniques ("+" indicates ML techniques outperform RA techniques, "-" indicates RA techniques outperform ML techniques; the number following the study ID is MMRE improvement in percentage, the study ID in bold indicates the improvement exceeds 5%)

ML technique		**RA techniques**
ANN	+	**S26**(13), **S26**(12), **S26**(5), **S26**(162), S26(4), **S26**(150), **S55**(190), **S33**(19), **S33**(17), **S33**(18), **S33**(16), **S43**(62), **S43**(50), **S43**(5), S43(4), **S44**(128), **S44**(75), **S44**(54), S44(4), **S44**(20), **S44**(130), S44(2), **S44**(77), **S44**(5), **S44**(21), **S44**(157), S44(3), **S44**(104), **S44**(13), **S44**(83), **S44**(30), S44(3), **S44**(19), **S44**(76), S44(1), **S44**(23), **S55**(206), **S57**(227), S57(2), **S58**(233.79), S58(1.41), **S58**(5.06), **S58**(233.36), **S58**(231.58), **S58**(5), **S58**(231.23), S58(3.8), **S58**(233.51), S58(3.59), **S55**(178), **S55**(194), **S57**(215), S57(1), **S58**(222.49), S58(0.31), S58(3.96), **S58**(222.06), **S58**(220.28), **S58**(219.93), S58(2.7), **S58**(222.21), S58(2.49), **S26**(5), **S55**(117), **S33**(11), **S44**(44), **S33**(9), **S55**(133), **S57**(154), **S58**(161.19), **S58**(160.76), **S58**(158.98), **S58**(158.63), **S58**(160.91), **S9**(75), **S55**(201), **S26**(15), **S33**(21), **S33**(19), S44(1), **S44**(128), **S52**(30), S52(1), **S52**(7), **S52**(17), **S52**(15), **S52**(26), S52(1), **S52**(11), **S52**(16), **S52**(24), **S52**(12), **S52**(6), **S52**(21), **S52**(15), **S52**(27), **S52**(9), **S52**(9), **S52**(20), **S52**(18), **S52**(29), S52(4), **S55**(217), S55(0), **S57**(238), S57(4), **S58**(245.19), S58(3.11), **S58**(244.76), **S58**(6.76), **S58**(242.98), **S58**(242.63), **S58**(5.5), **S58**(244.91), **S58**(5.29), **S44**(75), S68(1.95), **S68**(10.47), **S68**(6.48), **S68**(29.36), **S68**(5.43), **S68**(10.57), **S68**(14.01), **S68**(58.93), S68(0.02), **S68**(6.39), S68(1.71), **S69**(6.39), S69(1.71), **S69**(58.93), **S69**(14.01), **S69**(6.48), **S69**(29.36), **S69**(5.43), **S69**(10.57), S69(1.95), **S69**(10.47)
	-	S55(4), **S33**(37), S55(2), **S55**(5), **S33**(38), **S58**(6.87), S55(3), **S9**(9), **S9**(27), **S55**(12), **S33**(45), **S44**(9), **S44**(25), **S44**(422), **S55**(10), **S57**(6), **S58**(6.89), S58(3.24), **S58**(13.07), **S58**(5), S58(4.71), **S44**(27), **S44**(9), **S44**(63), **S44**(140), **S9**(17), S55(2), **S44**(15), **S44**(338), **S33**(35), **S52**(9), S58(3.07), **S44**(17), S69(1.32), S69(0.13), **S69**(23.01), **S69**(6.16), S69(0.02), **S69**(8.67), **S69**(7.75), **S69**(138.11), **S69**(143.6), S69(0.32), S69(3.69), **S69**(7.71), **S69**(5.91), S69(3.71), **S69**(5.1), **S69**(8.41), **S44**(53), **S44**(224), **S44**(18), **S44**(338), S44(2)**, S44**(20)**, S44**(56), **S44**(334)**, S44**(20), **S44**(532), S44(4), **S44**(66), **S44**(22), **S44**(119), **S44**(58), **S44**(214), **S44**(20), **S44**(412)**,** S44(4)**, S44**(22)**, S44**(58), **S44**(138)**, S44**(336)**, S44**(34), **S44**(111)**, S44**(309)**, S44**(33), **S44**(111)**,** S44(3), **S44**(383)**, S44**(5), **S44**(41), **S44**(185)**, S44**(390)**, S44**(35), **S44**(192), S68(1.32), S68(0.13), **S68**(23.01), **S68**(6.16), **S68**(8.67), **S68**(7.75), **S68**(138.11), **S68**(143.6), S68(0.32), S68(3.69), **S68**(7.71), **S68**(5.91), S68(3.71), **S68**(8.41), **S68**(5.1)

CBR	+	**S44**(5), **S44**(214), **S44**(5), **S44**(168)**, S44**(15), **S44**(130), **S44**(15), **S44**(84)**, S44**(12), **S44**(214)**, S44**(12), **S44**(168)**, S44**(10), **S44**(20)**, S44**(10)**, S44**(10), **S44**(140)**, S44**(10), **S44**(94)**, S44**(34), **S44**(216)**, S44**(34), **S44**(170)**, S44**(35), **S44**(243)**, S44**(35), **S44**(197)**, S44**(27), **S44**(169)**, S44**(27), **S44**(123)**, S44**(33), **S44**(162)**, S44**(33), **S44**(116)
	-	**S44**(37), **S44**(144)**, S44**(27), **S44**(228)**, S44**(30), **S44**(144)**, S44**(26)**, S44**(32), **S44**(338)**, S44**(32), **S44**(218)**, S44**(8), **S44**(142)**, S44**(7), **S44**(115)**, S44**(15), **S44**(189)**, S44**(9), **S44**(196)
IRB	+	**S44**(86), **S44**(175), S44(2), **S44**(91), **S44**(175), **S44**(86), **S44**(101), **S44**(12), **S44**(177), **S44**(6), **S44**(88), **S44**(204), **S44**(7), **S44**(115), **S44**(130), **S44**(41), **S44**(123), **S44**(5),**S44**(34)
	-	**S44**(23), **S44**(97), **S44**(260), **S44**(31), **S44**(13), **S44**(47), **S44**(344), **S44**(21), **S44**(50), **S44**(260), **S44**(24), **S44**(16), **S44**(52), **S44**(454), **S44**(26), **S44**(19), **S44**(18), **S44**(108), **S44**(52), **S44**(334), **S44**(26), **S44**(18), **S44**(28), **S44**(258), S44(2), **S44**(27), **S44**(231), S44(1), **S44**(35), **S44**(305), **S44**(9), **S44**(1), **S44**(29), **S44**(312), **S44**(3)
DT	+	**S6**(105), **S6**(93), **S21**(29), **S44**(141), **S44**(11), **S44**(130), **S21**(113), **S44**(12), S69(0), S69(1.55), S69(3.6), S69(1.52), S69(0), S69(2.31), **S69**(14.63), S69(1.52), S69(2.64), S69(3.54), S69(1.85), S69(0.7), S69(2.30), S69(0), S44(4), **S44**(46), **S44**(141), **S44**(11), S44(1), **S44**(130), **S44**(67), **S44**(56), **S44**(7), **S44**(143), **S44**(13), S44(3), **S44**(23), **S44**(132), **S44**(8), **S44**(170), **S44**(40), S44(4), **S44**(24), **S44**(159), S44(0), **S44**(96), **S44**(16), **S44**(85), **S44**(6), **S44**(89), S44(2), **S44**(22), **S44**(78), S68(0), S68(1.55), S68(0), S68(3.6), S68(1.52), S68(2.31), **S68**(14.63), S68(1.52), S68(2.64), S68(3.54), S68(1.85), S68(0.7), S68(0), S68(2.3)
	-	**S6**(9), **S33**(12), **S6**(10), **S33**(13), **S9**(309), **S9**(26), **S33**(20), **S21**(10), **S44**(22), **S44**(50), **S44**(26), **S44**(225), **S44**(6), **S9**(225), **S9**(16), **S33**(10), S21(0), **S44**(57), S69(1.34), S69(4.59), S69(2.37), **S69**(5.43), **S69**(111.02), **S69**(142.6), S69(2.88), S69(1.57), S69(3.09),**S69**(8.6), S69(3.36), S69(1.77), **S44**(40), **S44**(73), **S44**(16), **S44**(309), **S44**(15), **S44**(43), **S44**(19), **S44**(225), **S44**(17), **S44**(53), **S44**(45), **S44**(183), S44(1), **S44**(64), **S44**(21), **S44**(419), **S44**(17), **S44**(45), **S44**(64), S44(1), **S44**(21), **S44**(299), **S44**(21), **S44**(223), **S44**(20), **S44**(196), **S44**(28), **S44**(34), S44(4), **S44**(270), **S44**(22), **S44**(41), **S44**(277), S68(1.34), S68(4.59), S68(2.37), **S68**(5.43), **S68**(111.02), **S68**(142.6), S68(2.88), S68(1.57), S68(3.09), **S68**(8.6), S68(3.36), S68(1.77)
SVM/R	+	**S9**(18), **S44**(55), **S9**(102), **S44**(7), **S44**(139), **S68**(10.45), S68(0.38), S68(3.83), S68(1.54), **S68**(5.61), **S68**(23.49), **S68**(7.98), **S68**(9.02), S68(4.13), S68(4.3), **S68**(5.36), S68(3.07), **S68**(26.09), S68(3.71), S68(4.02), S68(0.06), S44(4), **S44**(139), S44(2), S44(2), **S44**(65), **S44**(26), **S44**(141), **S44**(27), **S44**(168), **S44**(19), **S44**(94), **S44**(25), **S44**(218)
	-	**S9**(11), S44(3), S9(1), S68(0.22), S68(1.8), **S68**(126.37), **S68**(85.79), S68(2.42), **S68**(6.1), S68(0.35), S68(4.05), S68(0.84), S68(3.6), **S44**(55)
FNF	+	**S56**(258), **S56**(246), **S69**(230.34), **S69**(6.55), **S69**(219.04), **S69**(5.45), **S44**(121), **S44**(5), **S42**(10), **S42**(134), **S44**(207), **S69**(157.74), **S44**(5), **S44**(33), **S44**(5), **S44**(121), **S69**(241.74), **S69**(8.25), S44(2), **S44**(205), S44(0), **S44**(11), S44(0), **S44**(131), **S44**(24), **S44**(207), **S44**(25), **S44**(234), **S44**(17), **S44**(160), **S44**(23), **S44**(153), S44(2), **S44**(205), S44(0), **S44**(11), S44(0), **S44**(131), **S44**(24), **S44**(207), **S44**(25), **S44**(234), **S44**(17), **S44**(160), **S44**(23), **S44**(153)
	-	**S44**(5), S69(1.75)

Table A-7. Comparison of MMRE between ML techniques ("+" indicates the technique given in the row outperforms the technique given in the column, "-" indicates the technique given in the column outperforms the technique given in the row; the number following the study ID is MMRE improvement in percentage, the study ID in bold indicates the improvement exceeds 5%)

		FNF	SVM/R	DT	IRB	BN	CBR
ANN	+	**S69**(9.43), **S69**(19.69), **S42**(50.40), **S42**(8.40), **S42**(17), **S42**(51.10), S69(0.64), **S69**(70.17), **S58**(64.19), S58(3.59), **S58**(63.76), S58(3.51), **S58**(61.63), **S58**(6.61), **S58**(63.91), S58(3.85),	**S38**(25), **S54**(25), **S58**(25), **S69**(25), **S58**(159), **S33**(22), **S33**(16.50), S69(0.16), **S69**(98.69), **S69**(94.69), **S33**(20), **S57**(136.50), **S57**(130.50), **S33**(28.30), **S69**(149.17), **S69**(7.64), **S69**(145.17), **S69**(8.64), **S58**(29), **S58**(24.60), **S68**(54.80), S68(4.99), **S68**(5.87), S68(2.10), S68(0.38), **S68**(6.27), **S68**(6.74), **S68**(5.55), S68(0.02), **S69**(29), **S58**(143.19), **S58**(10.59),	**S9**(300), **S21**(300), **S55**(84.49), **S55**(5.46), **S26**(57), **S26**(14.28), **S43**(42.20), **S43**(14.50), **S33**(26.3), **S43**(14.50), **S57**(122.30), **S57**(11.80), **S44**(64), **S44**(23), **S44**(117), **S44**(41), **S44**(25), **S38**(28), **S54**(17), **S58**(28), **S58**(156), **S44**(13), **S44**(85), **S44**(300), S44(1), **S44**(353), **S44**(17), **S44**(113), S44(1), **S33**(11,2), **S33**(21), **S33**(15.5), **S69**(87.69), **S33**(19), **S58**(46.70), **S33**(18.50),	**S44**(42), **S44**(335), **S44**(30), **S44**(120), **S44**(388), **S44**(48), **S44**(78), S44(32), S44(4), **S44**(22), **S44**(513), **S44**(6)	**S33**(24.20), S55(1.36), **S55**(27.89), S26(0.40), **S26**(10.18), S43(0.40), **S43**(10.18), S55(3.40), **S33**(24.20), S69(1.36), **S57**(65.70), **S57**(7.70), **S42**(95.40), **S33**(14,4), **S42**(31.40),	**S44**(219), **S44**(10), S44(4), **S44**(272), **S44**(28), **S44**(194), **S44**(12)

FNF	SVM/R	DT	IRB	BN	CBR
S58(61.98), S58(1.38) **S42**(18.30), **S42**(29)	**S58**(11.51), S58(3.59), **S58**(11.59), **S58**(142.76), S58(1.38), S58(3.51), **S58**(13.61), S58(3.85), **S58**(136.23), **S58**(136.63), **S58**(142.91), **S58**(138.51), **S58**(5.62), **S58**(140.98), **S58**(136.98)	**S58**(138.79), **S58**(139.19), **S58**(10.51), **S58**(138.36), **S58**(138.76), **S58**(140.63), **S58**(6.61), **S58**(14.61), **S58**(10.85), **S58**(139.91), **S58**(11.85), **S58**(136.58),	**S33**(22.80), **S58**(14.80), **S69**(14.80), **S69**(84.49), **S69**(5.46), **S56**(57), **S69**(18), **S55**(100.48), **S55**(7.50), **S69**(134.97), **S69**(13.94), **S58**(139.63), **S58**(24.61), **S58**(141.76), **S58**(21.51), **S58**(142.19), **S58**(21.59), **S69**(138.17), **S69**(6.64), **S58**(128.99), **S58**(16.89), **S58**(18), **S58**(132.19), **S58**(9.59), **S58**(128.56), **S58**(16.81), **S58**(131.76), **S58**(9.51), **S58**(139, 63), **S58**(12.61), **S58**(141.91), **S58**(21.85), **S58**(126.43), **S58**(19.91), **S58**(128.71), **S58**(17.15), **S58**(126.78), **S58**(11.92), **S58**(131.91), **S58**(9.85), **S58**(129.98), S58(4.62), **S58**(139.98), **S58**(16.62), S68(1.21), **S68**(10.98), S68(1.71), **S68**(56.62), S68(2.56), S68(4.96), **S68**(32.45), S68(2.69), **S68**(8.79), **S68**(12.34), S68(1.25), **S68**(10.47)		**S55**(43.88), **S69**(27.89), **S42**(96,10), **S42**(41.30), **S69**(78.37), **S69**(9.84), S56(0.40), **S52**(72.81), **S52**(12.79), **S52**(71.96), **S52**(72.11), **S52**(13.15), **S52**(70.18), **S52**(7.82), **S52**(12.71), **S52**(69.83), **S52**(15.81), **S33**(18.70)	

	FNF	SVM/R	DT	IRB	BN	CBR
-	**S69**(7.84), **S69**(119.74), **S69**(37.25), **S58**(23), **S69**(294.74), S44(4), **S69**(62.25), **S69**(41.05), **S69**(10.09), S69(1.61), **S44**(130), **S44**(22), **S44**(345), **S44**(58), **S44**(23), S44(4), **S44**(543), **S44**(20), **S44**(130), **S44**(22), **S44**(345), **S44**(58), **S44**(77), **S44**(543), **S44**(20), **S58**(106), **S58**(234), **S56**(96,79), **S58**(60), **S69**(234), **S69**(60), **S58**(50), **S58**(35), **S69**(50), **S69**(35)	**S44**(64), **S44**(24), **S38**(27), **S58**(27), **S54**(27), **S69**(27), **S38**(159), S69(0,84), **S38**(52), **S44**(60), **S44**(279), **S44**(6), **S54**(159), **S54**(52), **S58**(52), **S69**(159), **S69**(52), **S44**(11), **S44**(477), **S44**(22), **S9**(27), **S57**(27), **S57**(16), **S58**(27), **S58**(16), **S58**(31.40), **S58**(23), **S58**(31), **S58**(15), **S9**(16), **S58**(155), **S58**(53), **S58**(159.40), **S58**(60), **S69**(155), **S69**(53), **S21**(27), **S21**(16), **S58**(28), **S58**(35), **S68**(5.62), **S68**(5.49), **S68**(26.08), **S68**(19.70), S68(2), **S68**(5.94), S68(4), **S68**(8.73), **S68**(5.95), **S68**(11.74), **S68**(57.81), S68(3.34), **S68**(15.69), S68(1.86), **S68**(9.32), **S68**(6.64), **S68**(8.79), **S69**(28)	S9(1), S21(1), **S43**(42.20), **S44**(151), **S44**(13), **S44**(349), **S38**(17), **S44**(66), **S44**(35), **S54**(28), **S58**(17), **S38**(156), **S38**(42), **S44**(281), **S44**(41), **S54**(156), **S54**(42), **S58**(42), **S44**(13), **S44**(479), S44(3), **S44**(37), **S44**(55), **S44**(21), **S44**(270), **S44**(57), S44(2), S44(3), **S44**(468), **S44**(19), **S58**(28), **S58**(5), **S58**(38), **S58**(17), S69(1.84), **S58**(169.20), **S69**(46.70), **S69**(169.20), **S58**(166), **S58**(54), **S69**(166), **S69**(54), **S57**(41.20), **S57**(9.70), **S58**(41.20), **S58**(9.70), **S58**(21.70), **S69**(21.70), **S21**(31), **S21**(17), **S58**(29), **S69**(29), S68(1.32), **S68**(24.56), **S68**(9.76), S68(1.50), **S68**(6.30), S68(2.32), **S68**(27.09), S68(1), S68(0.62), S68(2.12), **S68**(10.35), **S68**(7.25), **S68**(6.95), **S68**(10.71)	**S44**(11), S44(4), **S44**(226), **S44**(40), **S44**(14), **S44**(424), S44(2), **S44**(6), **S44**(100), **S44**(315), **S44**(32), **S44**(47)	**S58**(225.80), **S58**(50.80), **S69**(225.80), **S69**(50.80), **S58**(41.80), **S57**(97.80), **S57**(13.80), **S58**(97.80), **S58**(13.80), **S58**(25.80), **S69**(41.80), **S69**(25.80)	**S44**(93), **S44**(32), **S44**(308), **S44**(68), **S44**(40), **S44**(14), **S44**(506), **S44**(30), **S44**(26), **S44**(139), **S44**(68), **S44**(32), **S44**(354), **S44**(86), **S44**(14), **S44**(552), **S44**(30)

		FNF	SVM/R	DT	IRB	BN	CBR
FNF	+	NA	**S58**(79), **S58**(7), **S69**(89), **S69**(7), **S69**(139.74), **S69**(9.25), **S44**(66), **S69**(135.74), **S44**(66), **S69**(10.75), **S58**(74.60), S58(0), **S58**(75), **S58**(8), **S69**(8), **S69**(75)	**S58**(64.80), **S58**(13.30), **S69**(64.80), **S69**(13.30), **S58**(68), **S58**(6), **S69**(68), **S69**(6), **S69**(125.54), S44(1), **S69**(15.55), **S58**(18), **S69**(128.74), **S69**(8,25), **S44**(64), **S44**(17), **S44**(194), **S44**(45), **S44**(194), **S44**(45), **S44**(64), **S44**(17), **S44**(430), **S44**(21), **S44**(430), **S44**(21), **S44**(75), S44(1), **S44**(75), **S56**(153.79), **S58**(78)	**S44**(119), **S44**(18), **S44**(465), **S44**(52), **S44**(465), **S44**(52), **S44**(30), **S44**(26), **S44**(30), **S44**(26), **S44**(119), **S44**(18)	**S42**(45), **S42**(23), **S56**(97.19), **S58**(8.20), **S58**(9.20), **S69**(8.20), **S69**(9.20), **S69**(68.94), **S69**(11.45)	**S44**(37), **S44**(37), **S44**(349), **S44**(32), **S44**(349), **S44**(32)
	-	NA	S44(2), S44(2)	NA	NA	NA	**S44**(9), **S44**(10), **S44**(9), **S44**(10), **S44**(10), **S44**(10)
SVM/R	+	NA	NA	**S21**(327), **S21**(15), S38(3), **S38**(10), **S44**(19), S54(3), **S54**(10), **S58**(11), S58(3.40), **S58**(8), S58(3), **S58**(10), **S44**(128), **S44**(364), **S44**(23), **S44**(47), **S44**(9), S44(3), **S9**(327), **S9**(15), **S33**(6,3), **S57**(6.30), **S58**(6.30), **S58**(5.30), **S69**(6.30), **S69**(5.30), **S58**(6), **S58**(13.30), S68(4.30), **S68**(6.70), S68(1.52), **S68**(30.68),	**S44**(53), **S4**(20), **S44**(399), **S44**(54), **S44**(28)	S33(20.20), S57(2.20), S58(2.20), **S58**(9.20), S58(1.20), S69(1.20), S69(2.20)	**S44**(283), **S44**(34)

		FNF	SVM/R	DT	IRB	BN	CBR
				S68(3.71), S68(2.50), S68(2.43), S68(3.63), S68(1.82), S68(1.22), **S68**(56.81), S68(2.52), S68(0.46), S68(4.58), **S68**(26.58), **S68**(5.34), S68(4.55), S68(2.07), **S68**(5.60), **S68**(10.45)			
	-	NA	NA	S44(2), S58(1), S33(1), **S58**(11), S58(1), **S69**(11), S69(1), **S57**(14.20), **S58**(14.20), **S58**(9.80), **S58(**10.20), **S69**(14.20), **S69**(10.20), **S21**(11), S21(1), **S58**(6.60), **S58**(7), S58(2), S68(3.82), **S68**(15.35), **S68**(5.61), S68(0.31), S68(4.30), S68(1.92), S69(2), **S69**(7)	**S44**(36)	**S57**(70.80), **S58**(70.80), **S58**(66.40), **S58**(66.80), **S69**(70.80), **S69**(66.80),	**S44**(75), **S44**(8), **S44**(29), **S44**(8),
DT	+		NA	NA	**S44**(401), **S44**(35), **S44**(271), **S44**(5), **S44**(25), **S44**(7), **S44**(35), **S44**(31), **S44**(390), **S44**(51), **S44**(34), **S44**(9), **S44**(164), **S44**(55), S44(1), **S44**(44),	S33(3.20), S58(3.20), S69(3.20)	**S44**(274), **S44**(31), **S44**(11), **S44**(285), **S44**(15), **S44**(155)

		FNF	SVM/R	DT	IRB	BN	CBR
					S44(17)		
	-		NA	NA	**S44**(45), **S44**(19), **S44**(400), **S44**(75), **S44**(27), **S44**(311), S44(3)	**S6**(56.60), S6(4.10), **S26**(56.60), S26(4.10), S33(4.40), **S43**(56.60), S43(4.10), **S55**(56.60), S55(4.10), **S56**(56.60), **S57**(56.60), S57(4.10), **S58**(56.60), S58(4.10), **S69**(56.60), S69(4.10), **S58**(69.80), **S58**(8.80), **S69**(59.80), **58**(59.80)	**S44**(81), **S44**(27), **S44**(439), **S44**(31), **S44**(84), **S44**(11), **S44**(73), **S44**(203), **S44**(55), **S44**(27), **S44**(157),**S44**(55), **S44**(27), **S44**(393), **S44**(31), **S44**(38), **S44**(11), **S44**(13)
IRB	+	NA	NA	NA	NA	NA	**S44**(230), **S44**(39), **S44**(14), **S44**(7), **S44**(319)
	-	NA	NA	NA	NA	NA	**S44**(128), **S44**(28), **S44**(82), **S44**(28), **S44**(62), **S44**(474),

		FNF	SVM/R	DT	IRB	BN	CBR
							S44(428), **S44**(62), **S44**(36), **S44**(116), **S44**(6), **S44**(20), **S44**(36)
BN	+	NA	NA	NA	NA	NA	NA
	-	NA	NA	NA	NA	NA	NA