EXTENDED RESULTS

A Robust Decision-Making Framework Based on Collaborative Agents

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Table 1 indicates the abbreviations used to refer to the employed decision making methods in both tables and graphical results. A detailed explanation on how to interpret the displayed graphs can be found in the main article.

### Table 1. Abbreviations list for the decision-making methods.

| Method | \( N_{LD\text{M}} \) | \( N_{CD\text{M}} \) | FDSS | P | D | M | V |
|--------|----------------|----------------|------|---|---|---|---|
| Abbreviation | L | N | F | \( \Omega_P \) | \( \Omega_D \) | \( \Omega_M \) | \( \Omega_V \) |

Numerical results are grouped as follows:

- Table 2 shows complete numerical results (for both training and validation) obtained over the DB0 [2] dataset;
- Table 3 shows complete numerical results (for both training and validation) obtained over the DB1 [3] dataset;
- Table 4 shows complete numerical results (for both training and validation) obtained over the DB2 [4] dataset;
- Table 5 shows complete numerical results (for both training and validation) obtained over the DB3 [5] dataset;

Each table has a column for results relative to the training phase and a column for those relative to the validation phase. These numerical values represent the evaluation metrics “accuracy” (ACC), “Root Mean Square Error” (RMSE) and “Area Under the ROC Curve” (AUC), as defined in the main article. Best results are displayed in boldface while second best values in blue.

Extended graphical results are grouped as follows:

- Figure 1 and 2 depict the ROC curves, for the training and validation processes respectively, obtained over the DB0 [2] dataset;
- Figure 3 and 4 depict the ROC curves, for the training and validation processes respectively, obtained over the DB1 [3] dataset;
- Figure 5 and 6 depict the ROC curves, for the training and validation processes respectively, obtained over the DB2 [4] dataset;
- Figure 7 and 8 depict the ROC curves, for the training and validation processes respectively, obtained over the DB3 [5] dataset;

Each figure contains 15 subfigures arranged in 3 rows and 5 columns. The top row depicts the graphical results of local decision-making processes (L), which are implemented with the neuroevolution approach, while the middle and bottom rows depict the graphical results of collaborative decision-making processes (N), which are implemented with the neuroevolution approach (mid row), FDSS, statistical operators, i.e. mean, median and maximum value, and the voting method (bottom row). On each column, the number of agents used can range from 2 to 6.

For the sake of reproducibility, the source code implementing our “RDMCA” framework and leading to the presented results is made available in [6].
### TABLE 2.
Numerical results of the training and validation process for the DB0 data set. This table contains the best two cooperative decision-making methods accuracy performance per number of agents (n) vs. the performance of the single agent case. A indicates that all the agents in the $RDM_{CA}$ system have the same collaborative decision-making method.

| n | DM ID | ACC  | RMSE | AUC  | DM ID | ACC  | RMSE | AUC  |
|---|-------|------|------|------|-------|------|------|------|
| 1 | L     | 0.8582 | 0.3766 | 0.8582 | L     | 0.7162 | 0.5327 | 0.7189 |
| 2 | N 1   | 0.8881 | 0.3024 | 0.9358 | N 2   | 0.7568 | 0.4932 | 0.7371 |
| 2 | N 2   | 0.8657 | 0.3665 | 0.8646 | N 1   | 0.6892 | 0.4752 | 0.6500 |
| 3 | N 1   | 0.8284 | 0.3740 | 0.8672 | N 2   | 0.6892 | 0.4752 | 0.6500 |
| 3 | N 2   | 0.8209 | 0.3730 | 0.8797 | F A   | 0.6892 | 0.4893 | 0.7258 |
| 4 | N 2   | 0.8881 | 0.2984 | 0.9550 | N 3   | 0.6757 | 0.5695 | 0.6902 |
| 4 | N 4   | 0.8881 | 0.2987 | 0.9552 | N 1   | 0.6622 | 0.4795 | 0.6652 |
| 5 | N 2   | 0.8731 | 0.3063 | 0.9345 | N 3   | 0.7027 | 0.4686 | 0.7318 |
| 5 | N 3   | 0.8731 | 0.3181 | 0.9240 | Ω D A | 0.7027 | 0.4751 | 0.7318 |
| 6 | N 4   | 0.8433 | 0.3314 | 0.9263 | N 1   | 0.7027 | 0.4769 | 0.7424 |
| 6 | N 5   | 0.8433 | 0.3447 | 0.9138 | F A   | 0.7027 | 0.4987 | 0.7144 |

### TABLE 3.
Numerical results of the training and validation process for the DB1 data set. This table contains the best two cooperative decision-making methods accuracy performance per number of agents (n) vs. the performance of the single agent case. A indicates that all the agents in the $RDM_{CA}$ system have the same collaborative decision-making method.

| n | DM ID | ACC  | RMSE | AUC  | DM ID | ACC  | RMSE | AUC  |
|---|-------|------|------|------|-------|------|------|------|
| 1 | L     | 0.8421 | 0.3974 | 0.8452 | L     | 0.5550 | 0.6671 | 0.7082 |
| 2 | N 1   | 0.9079 | 0.2925 | 0.9138 | N 1   | 0.6545 | 0.5076 | 0.6858 |
| 2 | N 2   | 0.8684 | 0.3352 | 0.8805 | N 1   | 0.6126 | 0.4147 | 0.6739 |
| 3 | N 2   | 0.8947 | 0.2901 | 0.9186 | N 1   | 0.7225 | 0.3722 | 0.7050 |
| 3 | N 1   | 0.8684 | 0.2900 | 0.9127 | N 1   | 0.7068 | 0.5566 | 0.7537 |
| 4 | N 4   | 0.8816 | 0.3236 | 0.9474 | F A   | 0.9110 | 0.4575 | 0.7684 |
| 4 | N 1   | 0.8684 | 0.3076 | 0.9443 | N 1   | 0.8482 | 0.3131 | 0.7441 |
| 5 | N 5   | 0.9079 | 0.2989 | 0.9307 | N 1   | 0.7435 | 0.3210 | 0.7880 |
| 5 | N 1   | 0.8553 | 0.3381 | 0.9193 | N 1   | 0.7382 | 0.4972 | 0.7693 |
| 6 | N 4   | 0.8947 | 0.3195 | 0.9086 | F A   | 0.8220 | 0.3107 | 0.7333 |
| 6 | N 3   | 0.8947 | 0.3199 | 0.9100 | F A   | 0.7225 | 0.4988 | 0.7831 |
| n  | DM | ID | ACC  | RMSE | AUC  | DM | ID | ACC  | RMSE | AUC  |
|----|----|----|------|------|------|----|----|------|------|------|
| 1  | L  | -  | 0.9426 | 0.2396 | 0.9550 | L  | -  | 0.9414 | 0.2442 | 0.9699 |
| 2  | N  | 2  | 0.9628 | 0.1928  | 0.9624 | ΩV | A  | 0.9377 | 0.2495 | 0.9268 |
| 3  | N  | 3  | 0.9616 | 0.2096  | 0.9555 | F  | A  | 0.9377 | 0.2630 | 0.9447 |
| 4  | N  | 1  | 0.9527 | 0.1948  | 0.9839 | N  | 2  | 0.9414 | 0.2421 | 0.9449 |
| 5  | N  | 3  | 0.9797 | 0.1298  | 0.9974 | ΩV | A  | 0.9414 | 0.2152 | 0.9802 |
| 6  | N  | 1  | 0.9730 | 0.1719  | 0.9933 | ΩD | A  | 0.9414 | 0.2273 | 0.9768 |
| 7  | N  | 2  | 0.7971 | 0.3822  | 0.8576 | N  | 1  | 0.9560 | 0.1988 | 0.9841 |
| 8  | N  | 3  | 0.8271 | 0.3584  | 0.8992 | ΩP | A  | 0.9414 | 0.2007 | 0.9807 |
| 9  | N  | 4  | 0.8271 | 0.3584  | 0.9007 | ΩP | A  | 0.9414 | 0.2152 | 0.9807 |
| 10 | N  | 6  | 0.9764 | 0.1571  | 0.9922 | ΩD | A  | 0.9414 | 0.2273 | 0.9768 |
| 11 | N  | 1  | 0.9730 | 0.1438  | 0.9954 | ΩD | A  | 0.9414 | 0.2152 | 0.9802 |

**TABLE 4.** Numerical results of the training and validation process for the DB2 data set. This table contains the best two cooperative decision-making methods accuracy performance per number of agents (n) vs. the performance of the single agent case. A indicates that all the agents in the RDMCA system have the same collaborative decision-making system.

| n  | DM | ID | ACC  | RMSE | AUC  | DM | ID | ACC  | RMSE | AUC  |
|----|----|----|------|------|------|----|----|------|------|------|
| 1  | L  | -  | 0.8186 | 0.4259 | 0.8186 | L  | -  | 0.7467 | 0.5033 | 0.7467 |
| 2  | N  | 1  | 0.7971 | 0.3887  | 0.8390 | N  | 2  | 0.7300 | 0.4380 | 0.7706 |
| 3  | N  | 2  | 0.7971 | 0.3887  | 0.8390 | N  | 1  | 0.7300 | 0.4391 | 0.7706 |
| 4  | N  | 3  | 0.7829 | 0.3822  | 0.8593 | N  | 3  | 0.7700 | 0.3927 | 0.8431 |
| 5  | N  | 2  | 0.7829 | 0.3822  | 0.8593 | N  | 2  | 0.7700 | 0.3930 | 0.8431 |
| 6  | N  | 4  | 0.7757 | 0.4455  | 0.8559 | N  | 4  | 0.7400 | 0.4144 | 0.8245 |
| 7  | N  | 3  | 0.7757 | 0.4455  | 0.8559 | N  | 2  | 0.7400 | 0.4204 | 0.8071 |
| 8  | N  | 4  | 0.8271 | 0.3580  | 0.8992 | N  | 5  | 0.7600 | 0.4147 | 0.8323 |
| 9  | N  | 3  | 0.8271 | 0.3580  | 0.8992 | ΩP | A  | 0.7633 | 0.4617 | 0.8260 |
| 10 | N  | 6  | 0.8014 | 0.3794  | 0.8824 | ΩP | A  | 0.7633 | 0.4323 | 0.8162 |

**TABLE 5.** Numerical results of the training and validation process for the DB3 data set. This table contains the best two cooperative decision-making methods accuracy performance per number of agents (n) vs. the performance of the single agent case. A indicates that all the agents in the RDMCA system have the same collaborative decision-making system.
FIGURE 1. ROC graphs of DB0 data set from systems with multiple agents (2, 3, 4, 5, and 6) on the training process.
FIGURE 2. ROC graphs of DB0 data set from systems with multiple agents (2, 3, 4, 5, and 6) on the validation process.
FIGURE 3. ROC graphs of DB1 data set from systems with multiple agents (2, 3, 4, 5, and 6) on the training process.
FIGURE 4. ROC graphs of DB1 data set from systems with multiple agents (2, 3, 4, 5, and 6) on the validation process.
FIGURE 5. ROC graphs of DB2 data set from systems with multiple agents (2, 3, 4, 5, and 6) on the training process.
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FIGURE 6. ROC graphs of DB2 data set from systems with multiple agents (2, 3, 4, 5, and 6) on the validation process.
FIGURE 7. ROC graphs of DB3 data set from systems with multiple agents (2, 3, 4, 5, and 6) on the training process.
FIGURE 8. ROC graphs of DB3 data set from systems with multiple agents (2, 3, 4, 5, and 6) on the validation process.
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