The PROSE (Protection System Evaluator) Model

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Abstract

The PROSE model is a combined GASP IV computer simulation to aid in the evaluation of protection systems. The primary systems that the PROSE model was designed for is the safeguarding of special nuclear fuel in transit or at a fixed site.

The method used in designing the PROSE study model was to simulate a small arms combat between a guard force and attacking adversaries. Discrete events include player and vehicle movement, engagement between two players, portal construction and penetration, player captures, and sensor detections. Observation between players and other plays and vehicles are represented with continuous state equations. In this decision, each player has a state variable representing the probability of detecting another entity. This probability is cumulated over time until a threshold is crossed. This state event then indicates that a detection has occurred, and the observing player has his perception updated which contains copies of the attributes values of the observed entity. Also, the perceived information is available to be communicated to other communication net members.

Individual and leader decisions are also simulated in the PROSE model. Individual decisions are based on the attribute values of perceived entities (including oneself). Existing situations are identified and responses are selected. For example, a situation might occur when the special nuclear material has been stolen, and the guard response might be to block the exist route of the adversaries. This type of decision making represents immediate responses, or standard operation procedures of the guards.

Leader planning or decision making is simulated by a different means. The leader of each force (guards and adversary) has the responsibility of organizing each subordinate's plans. The guard leaders perception is searched to determine if any adversaries are perceived to occupy "key" or vital locations. If so, then a response is selected. The responses might appear as movements of guard to "strategic" location in response to the occupancy of the "key" location. Adversary planning is somewhat different in that "goals" provide guidance for decision making. An adversary goal might be to secure the nuclear material room with these persons. If the adversary leader perceived that only two subordinates were in the process of achieving this goal, another subordinates (if possible) would be given the plan to move to the nuclear material room.

Statistics collection is an important part of the PROSE model design. Since this model was designed to an aid in evaluation of protection systems, several types of statistics are made avaiable to provide measures of the protection systems strengths and weaknesses. Some of these include firing accuracy, region occupancy, amount of information communicated, number of sensor detections, and whether or not plans were carried out properly.

1.0 INTRODUCTION

This report contains the description of the Protection System Evaluation (PROSE) model. This model was designed to assist in evaluating protection systems at installations (including transporters on the

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road) containing special nuclear material (SNM). It simulates armed encounters between small forces -- security force(s) guarding the SNM and one or more adversary forces whose goal is theft or sabotage of the SNM.

Contained in the report is a problem definition which describes the scope of the PROSE model and the overall objectives of the PROSE model. Next the data requirements and its internal representation is presented. This section of the report provides the reader with the necessary information needed to understand the model description. Next, the PROSE model description is presented. These sections of the report cover the definition of each event and the activity it represents. (Data is referred to extensively in these sections, so the reader should have an understanding of where this information is stored internally.) Finally, some special areas of the PROSE model are discussed in detail. These include activity duration, simulation of decison making, and output and statistic collection.

2.0 PROBLEM DEFINITION

The study of neutralization of adversary attacks against fixed nuclear sites or special nuclear material transporters involves small arms combat techniques. An overview of these techniques follows. Members of each side (guards and adversaries) move to strategic locations on the battlefield, where an engagement occurs or special tasks can be performed. Then, depending upon the results of the engagement or tasks, other strategic locations or tasks can be assigned to the members. This cycle of events continues until a terminating condition is satisfied. For the study of SNM safeguard, terminating condition occurs whenever the adversaries have gained access to the special nuclear material (SNM) and either have sabotaged it or removed it from the site. A second terminating condition occurs whenever the guards have successfully prevented the adversaries from accomplishing their goal.

The PROSE model is designed to be a package of FORTRAN subroutines linked with those in the GASP IV simulation language. It includes the representation of individual guards and adversaries (referred to as players). Each guard is a member of a force in which there is a leader, who is a leader, who is a participant in the combat with the added responsibility of organization of individual guard actions. Any number of guard forces are permissable but organization of effort cannot be performed between forces. For example, an auxiliary guard force might be represented as a separate force rather than as members of the existing force but not currently located on the site. These guards can only receive orders from the leader of the force they are a member of. In this case, these players could not receive orders from a leader on the site but must wait for the auxiliary force leader to issue orders.

The adversary organization is similar to that of the guards. Each adversary is a member of a force in which there is a leader who is a participant in the combat with the added responsibility of organization of individual adversary actions. Any number of adversary forces are permissable and each will have specific goals to accomplish. Organization between forces is represented through the successful completion of goals.

Below is a brief description of each activity represented in the PROSE model. Movement or the relocation of players (both guards and adversaries) involves a movement velocity and destination. A player's movement is monitored along a path from his current location to the destination. The destination and path are determined from the site description.

The site description is composed of point locations in which all players know the whereabouts and labels are given to these points to facilitate planning and location identification. Each point is contained within a region having uniform line of sight characteristics and uniform terrain features. Links between the point locations represent travel arcs. Any combination of these travel arcs constitute a movement path.

Buildings are also included in the site description. They block line of sight and movement except through portals (doors and windows). Building interiors are represented by restricted movement and special line of sight characteristics.

Vehicles are also included in the PROSE model. The presence of a vehicle on the site interferes with line of sight and movement paths. But this interference is dynamic and depends upon relocation of the vehicle. In some ways, vehicles can be thought of as movable buildings. Also, vehicles can be used to relocate players, who mount and dismount vehicles according to movement criterion.

This study also includes representation of individual engagement. A player can select to fire at another player if line of sight exists and a weapon is available. Each round (or burst) fired is assessed using a bivariate normal distribution to determine the target damage.

Other activities beside movement and engagement include barrier penetration, handling of equipment, sensor deactivation, activated delays, and capturing of players. Each of these activities consumes some interval of time which is dependent upon the number of players involved. Upon expiration of the interval of time, the activity is complete and other activities can be selected to be performed. Players performing an activity other than movement are restricted in movement but can engage if they choose.

Individual detections and communications are represented in the PROSE model. Detections are determined from the existence of line of sight and player actions. Whenever a detection is made, the observing guard or adversary updates a perception of the observed entity (either a player, vehicle, of sensor) and then the perceived information is available to be transmitted over the communication nets.

Communication is represented as a delay of information. Information received from observation is delayed before communication net members can receive it. Once this information is received it is used to update perceptions just as if it were a direct observation.

The perceptions built from the combination of observation and communication provide the basis for decision making. These perceptions contain attribute values of players, sensors, or vehicles, and combinations of these values are used to define specific situations. When a situation is perceived, a player has a chance to respond to it by performing any of the activities described above.

To complete the problem definition or scope of the PROSE model, one last topic needs to be discussed. This topic is the organization or leader planning of individual players. As described above, individual players have the capability to respond to immediate situations, but an overall organization is necessary to achieve plans or goals. Therefore, the purpose of leader planning is to coordinate individual decision making. This is accomplished by allowing the leader of a force the opportunity to communicate plans or desired actions to each subordinate on the force. The transmission of plans allows the capability to simulate defend and attack strategies.

This completes the discussion of the problem definition. This problem definition has provided a general idea of the relationship of entities and activities. In the following sections this relationship will be discussed in more detail. Next, the overall objective of the PROSE model and the PROSE model data requirement is presented.

3.0 OBJECTIVES

The objectives of the PROSE model are:

1. To provide a methodology for the study of neutralization of adversary attacks against fixed nuclear sites of special nuclear material transporters.

2. To provide a tool in which existing models can be linked together to provide a method for overall analysis.

3. To enable a user to statistically analyze an engagement so that "optimal" strategies for defense can be identified.

4.0 DATA DESIGN

The PROSE model contains two types of data, entity/attribute data and player performance data. Each is discussed below.

4.1 Entity/Attribute Data

Entity/attribute data includes all of the entities represented in the model with their attributes. Two-dimensional FORTRAN arrays contain this information, with the row index of these arrays as the entity number and the column index as the field or attribute number.

In order to store or retrieve information from the entity data arrays, the array name with the appropriate row and column indices are needed. For example, to find the physical status of player 6, the following expression must be used:

STATUS = PERSON(6,4)

PERSON is the name given to the FORTRAN array containing the information about players, and column or field 4 contains the players physical status.

The attribute values stored in the entity arrays are of three types: integer, real values, and record references. Some attributes contain integer values such as a person's physical status attribute. Physical status can indicate dead, captured major wound, minor wound or unharmed. Depending upon the physical status value, a player has different performance characteristics. Thus the physical status attribute contains integer value to be used as indices to the performance data. Other attributes have real values. For example, a player's posture can be a real value from 0.0(prone) to 1.0(erect). These values are used in the program just as they are stored to make comparisons for situations. As an illustration of how a real value is used, consider the cover attribute of a resion. This attribute contains a real value between 0.0(no cover) and 1.0(complete cover). By comparing a player's posture to the cover of the region he is located in, an exposure of the player can be determined. The final type of data stored in attribute are record references. These references are used whenever a list of elements could be referred to. For example, consider a player's equipment attribute, which could be a list of different types of equipment. The value stored in the player's equipment attribute would indicate the first equipment records describing the equipment carried by the players. Subsequent equipment records would be reference from an attribute of previous records. This attribute which contains the next element on the list is described with other attributes definition. In some cases, GASP IV files are used to save lists of entities. These files contain the record references contained on the list. An example of GASP IV file usage is for members of a force. Since players can both be on force members list and on communication net membership lists, the technique of a "next element on the list" attribute would not be adequate. Therefore, a separate storage design is necessary and the GASP IV file capability satisfies this need.

The data design has been purposely left in the text because of its importance to understanding the event design. Also, when the FORTRAN code is developed for the PROSE model, it is the responsibility of the programmer and user to know the type of data stored in each attribute. The FORTRAN code must account for the difference between a real value and a record reference stored in an attribute value.

4.2 Terrain Representation

The terrain representation in combat models must serve several purposes. First, it must provide a means to specify the locations of players, vehicle and sensors. Second, movement paths between positions on the site must be determinable. Third, it must provide for the representation of barriers (constraining either line of sight of movement) on the site.

The terrain representation designed for the PROSE model uses nodes and barriers. Nodes although defined as points on the site, represent regions of the site. The nodes are defined as the center of a region with boundaries half the distance to any of its neighboring nodes. Each node has as attribute values not only the center of the region, but also all of the characteristics of the region.

When defining the nodes (i.e. regions) of a site, two constraints must be observed. First the region about each node must have uniform line of sight characteristics. All points within a region must have a line of sight to all other points of the region. Also, line of sight between regions is uniform. That is, if line of sight exists between two regions, then any point in one region has line of sight with any point in the other region.

The second constraint to observe when defining nodes (regions) concerns the movement of players and vehicles. Only points at which a player or vehicle can change direction in movement are nodes. Movement paths are defined by specifying the successor nodes of each node. Also, nodes should be defined at points on the site where restricted movement is present. Portals within barriers are examples of this. One last constraint used in defining nodes is that nodes should be defined for all points of strategic interest on the site to be studied. For example, the special nuclear material room should contain at least one node with at least one path into it and out of it.

4.3 Line of Sight Representation

The topography of the site is represented through the line of sight between regions. If two regions do not have line of sight, then it might be because of dense brush or a hill. But in any case, a player in one of these regions cannot detect anything in the other region.

The line of sight information is stored in a FORTRAN array dimensioned by the nujber of nodes on the site. Each entry in the array defines the line of sight from one region (corresponding to the row number) to another region (corresponding to the column number). A zero or non-zero entry in the array indicates respectively the non-existence of line of sight between any two nodes.

A dynamic calculation of line of sight between two players can be used in the neutralization model. The calculation uses a simple line and plane intersection routine. The lines are determined from the (x,y,z) location of the players and the planes are the barriers. If the line intersects a barrier with opaque visibility, then line of sight is interrupted. Otherwise line of sight is considered to exist except when the regions two players are located do not have line of sight.

Each player in the game has a line of sight list. This list contains the identification of those players which he has line of sight to at any time of the simulation, and this list is maintained after each posture change or player movement. Whenever a player's posture has a value lower than the cover of the region he occupies, then he caqnot be observed nor can he observe anything. Whenever a player moves into a new region, his list of entities he has line of sight with is adjusted. This adjustment uses the line of sight relationship between regions and also dynamic calculation to determine if a barrier interrupts the line of sight. Also, whenever a player moves to the node (point definition), dynamic line of sight is recalculated for this player.

4.4 Communication Representation

The communication net (or nets) over which a player can send messages is (are) identified in the PLAYER attributes. A player can send messages containing attribute information about players, vehicles or sensors he has perceived over any communication net of which he is a member. Whenever one player detects another, a decision rule is used to determine which attribute information of the detected player is sent over which (if any) communication nets. Human factor limitations are used to govern the message sending process.

The list of players who can receive from a communication net is contained as one of the nets attributes. Whenever a message is added to the net, any player listed as a receiver is eligible to receive this information. But a player cannot receive the message until the net's delay time has expired. This time delay of a communication net represents the average traffic density on the net. When a message is added to a net, the delay time is added to the current simulation time to determine when the message will be available for reception. Upon expiration of this time, the information contained in the message is used to update the perceptions of the receiving players.

4.5 Player Action Representation

Player actions are represented with (one or more) discrete events. Completion of an event indicates that part or all of a player's action is complete. The completion of actions is discussed in section 7.0.

One of the PLAYER attributes is the player's current activity (an action number). he action attributes are the type and various type dependent parameters. From the type and parameters of the action reference by a player's attribute, the event type and duration time are determined.

Each player's activity is represented by one or more scheduled events. In the PROSE model, a player is considered to be performing the activity until either the event occurs or he is interrupted. In either case, whenever a player activity is reviewed the state variable affected by the type of action, determined from the event type, are updated to record the proportion of the activity which has been completed.

No simulation time elapses between the end of one event and the start of the next. Thus, undisturbed performance is represented by scheduling different subsequent event types.

4.6 Performance Data

Performance data includes guidelines which control the actions ofthe players. Examples of performance data are running speed of players, information used in target selection, and a rate for which information which can be assimimilated. This data is dependent upon human factor analysis. Experiments or existing studies should be used in supplying the performance data.

5.0 EVENT LIST

Below is a list of events that are used in the PROSE model with a brief definition of each. This list of events is complete and covers all of the processes represented in the neutralization problem.

A *movement event* occurs whenever a player completes or is interrupted in movement. It updates the player's location and line of sight. Also, checks for captures and sensor activations are performed.

An *engagement event* occurs whenever a round (or burst) arrives at a target. It assesses the damage to the target and interrupts the target to allow reaction to the fire.

A *portal penetration event* occurs whenever a portal has been penetrated, or whenever one of the players working on the portal is interrupted. It determines how much of the portal has been penetrated. If penetration is complete, the status of the portal is updated appropriately.

An *equipment removal event* occurs whenever equipment has been transferred, or whenever one of the players working on moving the equipment is interrupted. The location of the equipment is updated.

A *capture event* occurs whenever a capture has been completed. It removes the surrendering player from the game.

A *posture event* occurs whenever a player changes his posture. It updates the posture attribute of the player and adjusts line of sight characteristics.

A *detection event* occurs whenever a player detects another. It causes a perception event, updating the detecting player's perception.

A *sensor detection event* occurs whenever the sensor monitor receives a signal that a sensor has been tripped. It identifies the values of the attributes of the detected entity.

A *communication event* occurs whenever a player receives a message from a communication net. It identifies the values of the attribute of the subject of the message.

A *perception event* occurs whenever a player's perception needs to be updated. It uses the attributes obtained from detection, communication, or sensor detection to update the player's perception.

An *individual decision event* occurs whenever a player needs to review his current situation. It identifies the situation and selects a response which is the player's next activity.

A *leader planning event* occurs whenever a leader needs to review his force's current situation. It identifies the situation and selects a response. Subordinate members of the force are communicated plans in accordance with the response.

A *forced vehicle stop event* occurs whenever a vehicle has stopped because of an engagement. It assesses the damage to the occupants.

An *arrive event* occurs whenever the response force arrives. It adds the members of the force to the list of active players.

An *interaction event* occurs for a target of another player's fire, detects an unfriendly player, or moves into a region occupied by unfriendly players. It determines if the player should be interrupted. If not, then the player continues with the normal event sequence. Otherwise, the player is interrupted. His perception is updated, and an individual player decision event is scheduled for the player.

5.1 Event Codes

The event codes in the GASP IV neutralization model are derived from an independent event approach. Exhibit 5-1 contains the event code definition. This design uses only one event code for each activity. This requires that for each activity a player decides to perform, an event must be scheduled, and for simultaneous events are scheduled which might have different duration times for completion.

For example, consider a player who wants to engage a target, change his posture, and observe. Each of these activities will have a duration associated with it. A posture event, an engagement event, and detection event will be scheduled for the player. If the posture event requires the least time, then this event will occur first. Hence, when the player completes the engagement or detection events, his posture will be the new posture.

Also, if this player is a target, the player observing or firing at him would use the new posture. This posture is used in calculation of the probability of detection or probability of hit.

6.0 STATISTICS COLLECTION

To conduct studies with the PROSE model, statistics more detailed than the simple outcome (adversary/friendly success) of a replication must be available. For example, achieved accuracy and histories of weapons utilization would be of use in a study of guard armament. Below is a tentative list of statistics that can be collected in the PROSE model, including a brief explanation of how each statistic can be collected.

6.1 Status of Players

When interpreting the output of the simulation, users of the model will probably find it useful to inspect the status of players as dead, captured, incapacitated, or unharmed (neither wounded nor captured). A player's physical status can change because of fire, capture, or vehicle crash. A brief message describing the reason for a physical status change can be printed at the time of the change, and the number of casualties for the guards and adversaries accumulated.

Whenever a player is wounded or killed, a message should be printed.[1] An example of the message follows.

> At time 1.30, Guard 6 fires and kills Adversary 3 with 2 separate rounds. Four adversaries remain.

All of the information is known in the fire event except the number of subsequent rounds fired at a target before damage resulted. This value must be incremented each time a player fires at the same target without interruption.

Whenever a player is captured, the number of captures is incremented for the appropriate side and a message describing the event is printed. An example of the message follows:

> At time 2.30, Guard 3 successfully captures Adversary 1.
> Two adversaries remain.

Whenever a player is killed because of a vehicle crash, the number of vehicle crach is incremented. This total is kept for both the guards and adversaries. Also, a message will be printed describing the event, e.g. --

> At time 0.43, Guards 3 and 5 were killed when vehicle 1 crashed.
> Five guards still remain.

At the termination of a simulation run, the scoreboard of casualties is displayed. This includes the total number of fire wounds and kills, captures and vehicle accident victims for both the guards and adversaries. Also, a percentage for each casualty cause will be displayed.

Firing Accuracy

The statistic collection of firing accuracy records the total number of rounds fired by each player, the number of wounds and the number of kills.

At the termination of a simulation run, firing accuracy for each player is displayed. This report includes the percentage and total of misses, wounds, and kills for each player, along with results cumulated for the guards and adversaries.

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[1] This, and the other detailed statistics defined in this section, should be controlled by an input switch, by which the user can inhibit the potentially voluminous output associated with them.

6.3 Activity Utilization

Each player must be performing one of five activities: moving, firing, barrier penetration, material handling, and observation. The activity utilization statistic is the distribution of a player's time among these activities.

The collection method is to record the last time a player completed an activity is cumulated by subtracting the recorded time for the clock time at the change.

Whenever an engagement occurs, the cumulative time the player spends firing is updated. This cumulation involves calculating the elapsed time since the last update. This elapsed time is calculated by subtracting the current game time from the last time the player completed an activity. This time is then added to the total time spent firing. Then, the last time the player completed an activity can be updated to the current time.

The procedure for updating the activity utilization statistic is identical for movement, barrier penetration, and equipment removal, except a different counter is incremented in each case.

The observation activity is a default activity. If a player does not perform any of the above four activities, he can then be considered to be observing. Thus, the total time spent observing can be determined from the termination time and the total of the cumulative time moving, firing, penetrating barriers, and material handling.

At the termination of a simulation run, the cumulative time and percentage for each activity are reported. This report would include each player's activity utilization, the guards' activity utilization, and the adversaries utilization.

6.4 Distance Moved

For each player the cumulative distance moved can be recorded. Each time a player moves, the distance moved is calculated, and the total distance can be incremented for that player.

At the termination of a simulation run, a report is displayed including the cumulative distance moved for each player and totals for the guards and the adversaries.

6.5 Occupancy of Regions

The average occupancy of each group region (around a node) on the batterfield by adversaries and friendlies is of interest, especially when a region is a good vantage point or is occupied by an SNM transporter. The storage needed to gather some kinds of occupancy statistics can be very voluminous, but the storage requirements are not so great to accumulate the time integral of the number of occupants in each region; i.e., the number of person-seconds each region is occupied.

For each region it is necessary to maintain a running total of the occupancy and the last time this total was updated. Then, when a person leaves a region, the integrals can be incremented by the number of personnel multiplied by the occupancy time for the region exited and the region entered. The number of occupants and the time can be updated for these regions then. This statistic could be maintained for guard occupancy, adversary occupancy, and total players.

At the termination of simulation run, the average number of guards, adversaries, and total players occupying each region are displayed.

6.6 Successful Completion of Plans

Because plans are the source of a force's coordinated actions, it is of interest to know when a player completes a plan. At the time a player completes a plan, a printed description of the plan is to be printed.

When a player successfully penetrates a barrier, the following message is displayed. The elapsed time referred to below is the activity time used in the cumulation of barrier penetration time.

> At time 1.37, Adversaries, 3,4 and 5 have successfully penetrated portol 4. Elapsed time was 35 seconds.

When a player successfully moves equipment, the message below is displayed.

> At time 3.47, Adversaries 1 and 2 have successfully moved equipment DNM from node 7 to node 31.

6.7 Number of Detections

The total number of guards observed and the total number of adversaries observed is recorded for each player, with no distinction made between the member of a side. Whenever a player detects another, the cumulation is only dependent upon the side of which the detected player is a member.

At the termination of a simulation run, the total number of detections, the percentage that was of guards, and the percentage that was of of adversaries are displayed for each player.

6.8 Amount of Information Processed

The information received is a separate statistic from detection and communication. Each time a player detect an other, the number of attributes observed about that player is determined. The total number of attributes learned from detection is proposed as a measure of information received.

The same procedure is applied to information received from communication. Each time a player receives a message, the number of attributes which is learned about the subject of the message is determined. This number of attributes can be added to the total received from communication.

Each time a person identifies attributes of another player from either detection or communication, his perception is updated. Whenever this occurs, the cumulation of the number of attributes obtained from observation and communication is performed.

At the termination of a simulation run, the amount of information processed for each player is displayed. This report includes the total number of attributes perceived and the percentage received from detection and communication. Also, the rate of attributes assimilated per unit time is determined by dividing the total number of attributes perceived by the game time and is included in this report.

6.9 Time Between Detection

Whenever a player makes a detection of another, the time between detections is updated. The time of the last detection can be maintained and can be determined from the current game time minus the last detection time. This elapsed time can be used to update a minimum and maximum value. The player's last detection time can be updated to the curreng game time, and the elapsed time added onto a total.

At the termination of a simulation run, the average time between detection can be computed from the total duration of the simulation run divided by the number of detection and displayed. Also, the minimum and maximum time are displayed for each player.

6.10 Execution of Orders

The number of times players make decisions to follow plans, not to follow plans, or in the absence of plans is a potentially useful statistic. A counter can be incremented each time a player makes a decision, and, if the decision was to follow a given plan, a second counter is incremented. If the decision was not to follow a given plan (i.e., plan given to move but instead player fired), a third counter is incremented; and if the player did not have any plans to follow, a fourth counter is incremented.

At the termination of a simulation run, the total number of decisions made by each is displayed. Also, the percentage of decisions made to follow a given plan; the percentage of decisions made not to follow a plan; and the percentage of decisions made without any plan to follow are displayed for each player.

6.11 Leader Decisions

Leader decisions are the source of plans to be followed by individual players. It is proposed that the assignment of plans to players be accomplished by the printing of a message such as the one below.

> At time 0.27, Guard leader
> orders Guards 2, 3, and 4 to
> move to node 38.

This message might conveniently be generated whenever the orders are transmitted to the subordinates.

6.12 Number of Communications Received

The total number of communications received about guards and adversaries is recorded for each player. As in the case of detection, there is to be no distinction made between members of a side. Whenever a player receives a communication about another, the cumulation is only dependent upon the side of which the detected player is a member.

At the termination of a simulation run the total number of communications received, the percentage that was of guards, and the percentage that was of adversaries are displayed for each player.

6.13 Time Between Communications Received

Whenever a player receives a message, the time between communications received is updated. The time of the last message received can be maintained. The last time a communication was received would be subtracted from the current game time to determine the time between communications received. This elapsed time will be cumulated time between communications received divided by the number of communications received. Also, the minimum and maximum times are displayed for each player.

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