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A methodology for state and transitional analysis of the M1A2 Abrams driver's instrument panel

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THESIS

A METHODOLOGY FOR STATE AND TRANSITIONAL ANALYSIS OF THE M1A2 ABRAMS DRIVER'S INSTRUMENT PANEL

by

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and
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September 2002

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requirements for the degree of

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This thesis is an independent study to conduct a detailed problem analysis to determine if a methodology can be derived to map the states of the M1A2 simulator to specific doctrinal tasks. Specifically, what are Tactics, Techniques and Procedures (TTP); Crew Drills; and Battle Drills and can they be mapped to specific states of the M1A2 simulator? If so, then demonstrate such a methodology using a small subset of the M1A2 simulator stimuli and a given doctrinal task. Additionally, to identify problem areas associated with state to task mapping, such as 'state explosion' and recommend a possible solution. We conclude through our research that a methodology can be derived and have demonstrated that it is reasonable to take input in the form of stimuli from the driver's instrument panel and evaluate current state and anticipate future states within the context of a given tactical or training scenario.

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TABLE OF CONTENTS

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LIST OF FIGURES

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LIST OF TABLES

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This thesis would not have been possible if not for the support, and input of Dr. Michael Saboe. We offer our sincere thanks to Dr. Saboe for his guidance during the early portion of our research. Dr. Saboe's support was crucial to us completing what we feel is the beginning of an interesting project. It was an honor for us to work with a professional like Dr. Saboe. His vast experiences and knowledge was valuable to us in developing the concept we present in this thesis. His experiences include: Army Senior Software Engineer, Senior engineer, analyst, Senior analyst/ engineer. Dr. Saboe's list of awards and achievements is equally impressive. His awards and achievements include:

Office of the Secretary of Defense Excellence Award

Joint Logistics Commanders Certificate of Merit (26 star - awarded twice)

Achievement medal for Civilian Service

Commanders Award for Civilian Service

IEEE Certified Software Engineer – one of the 1st 100 in the world

Certified Acquisition Professional

National Academy of Sciences, National Research Council

Physics Honor Society ΣΠΣ,

American Institute of Physics member 1975-

American Society of Mechanical Engineers

American Institute of Aeronautics and Astronautics

Vehicular Advanced Software Technology Consortium - Chair

Great Lakes Software Process Improvement Network - Board member

Every year, consistently exceeded performance standards

Professional Advisory Boards, Engineering

University of Michigan , Dearborn

Oakland University

Strategic Advisory Board, Information technology Futures

University of Detroit Mercy

We feel it is equally important to note that Dr. Saboe was responsible for several publications and significant contributions to include:

39 Major Initiatives

10 Key Workshops

15 Articles and Publications

26 Books, Reports and Contract Software

16 Proceedings

Our relationship with Dr. Saboe was fluid and frequent. We will remember Dr. Saboe for the continuous mentorship and direction he provided us. Sadly, midway through our research Dr. Saboe passed away. Dr. Saboe will not only be missed by his family and friends, he will be greatly missed by us.

I. INTRODUCTION

A. BACKGROUND

Dr. Mike Saboe asked us to conduct an independent study to research and derive a methodology to facilitate the mapping of M1A2 related doctrinal tasks to the states of an M1A2 simulator. He initially asked us to explore the possibility of deriving a method for a one-to-one mapping between simulation states to doctrinal tactics, techniques and procedures and if this approach was not feasible, to then recommend an alternative approach.

Because this research did not fall within the framework of an existing project, defining the bounds of this research proved to be quite a challenge. Dr. Saboe gave us great latitude to facilitate the process of discovery as we conducted problem analysis. From the onset of our initial discussions with Dr. Saboe, it was evident that it would be necessary for us to include a brief synopsis of the terminology and dynamic nature of Army Doctrine. Dr. Saboe asked us to include this synopsis into our thesis for the benefit of future researchers. Additionally, we recognized very early that the scope of this research would need to be significantly narrowed in order to adequately demonstrate a methodology for mapping states to doctrinal tasks as well as demonstrate a method for reducing the state explosion problem associated with state translations. Dr. Saboe asked us to identify a simple doctrinal task and only those stimuli associated with that task in order to do so.

A necessary part of our research was to observe the conduct of driver's training at the Armor school located in Ft. Knox, Kentucky. We established what we felt were important objectives to achieve during this fact finding trip to help us better shape the direction of our research. Our objectives were to attend a driver's trainer orientation, observe students operate the driver's trainer, and finally operate the driver's trainer.

In addition to observing driver's training being conducted, we interviewed students going through the training. By interviewing some of the students we were able to ascertain what the driver experiences when he enters the driver's compartment and an overall impression about the training and feedback each driver receives. The general consensus was that the tank simulator was relatively easy to operate and it was responsive. It appears that most drivers learn how to operate the M1A2 very quickly.

The goal of the Tank Driver Simulator is to facilitate the development of both basic and advanced driving skills. In order to develop these skills, the driver is trained in all types of terrain, visibility and weather. In addition the driver is trained in additional tasks such as how to handle malfunctions to enemy fire. The students are required to negotiate twenty-one scenarios designed to increase proficiency as the scenario level increases. Each driver is trained in ten specific areas. These areas include:

- AVLB Crossing
- Convoy Driving
- Roadmarch Driving
- Motorpool with Ground Guides
- Formation Driving
- Water Fording
- Night Driving
- Night Periscope Driving
- Rail load with Ground Guides
- Minefield – Marked and Unmarked

The driver receives specific queues from the driver's instrument panel which prompts him to respond in a manner prescribe by the trainer. Identifying these prescribed responses was another goal we wanted to achieve during the fact finding trip. What was discovered is that for each scenario there were prescribe responses expected from the driver, based on the situation he was confronted with. In some cases the responses followed a specific order. In other cases the order of the responses was not important. Finally we wanted to verify if the simulator accurately represented an actual M1A1 or M1A2 Abrams Tank and provide the driver with a realistic training environment. What we discovered was that the representation of the simulator was accurate and that the driver is thoroughly trained in the simulator prior to driving the actual tank.

B. PROJECT DESCRIPTION

Our approach to this thesis is relatively simple. The first thing we had to do was provide a clear understanding of what doctrine was because during our problem analysis it was apparent that there was a lack of understanding of what doctrine represents. The misconception was that doctrine was a sequential series of steps that could be represented by a one-to-one state relationship. It became very clear to us that a portion of our thesis had to define doctrinal context in order to resolve this misconception. After defining doctrine, we established a "road map" which outlined our proposed methodology. We describe each step of our proposed methodology in detail while maintaining a certain level of abstraction. We want to remain at a certain level of abstraction in order to preserve the fluid nature of our methodology. Our goal, with the proposed methodology, is not to suggest a specific application however, through demonstration we describe our methodology with a select set of stimuli and a specific task to show this methodology may be applied. Given a specific task, we will describe a set of stimuli as it is seen within a M1A2 driver's instrument panel as it might be represented in a simulator. In addition we will describe the set of stimuli as we represent it in a data structure.

We suggest that our methodology will facilitate the interpretation of stimuli on the driver's instrument panel of the M1A2 simulator. A key factor in our methodology is describing and demonstrating the decomposition of complex stimuli. And by example, we demonstrate the results of decomposing complex stimuli. In addition we present a possible solution to mitigating state explosion by introducing rules. In order to demonstrate our methodology, we have to describe a suitable doctrinal task for demonstration. We had to identify a task consisting of a small set of stimuli that would enable us to accomplish the following things:

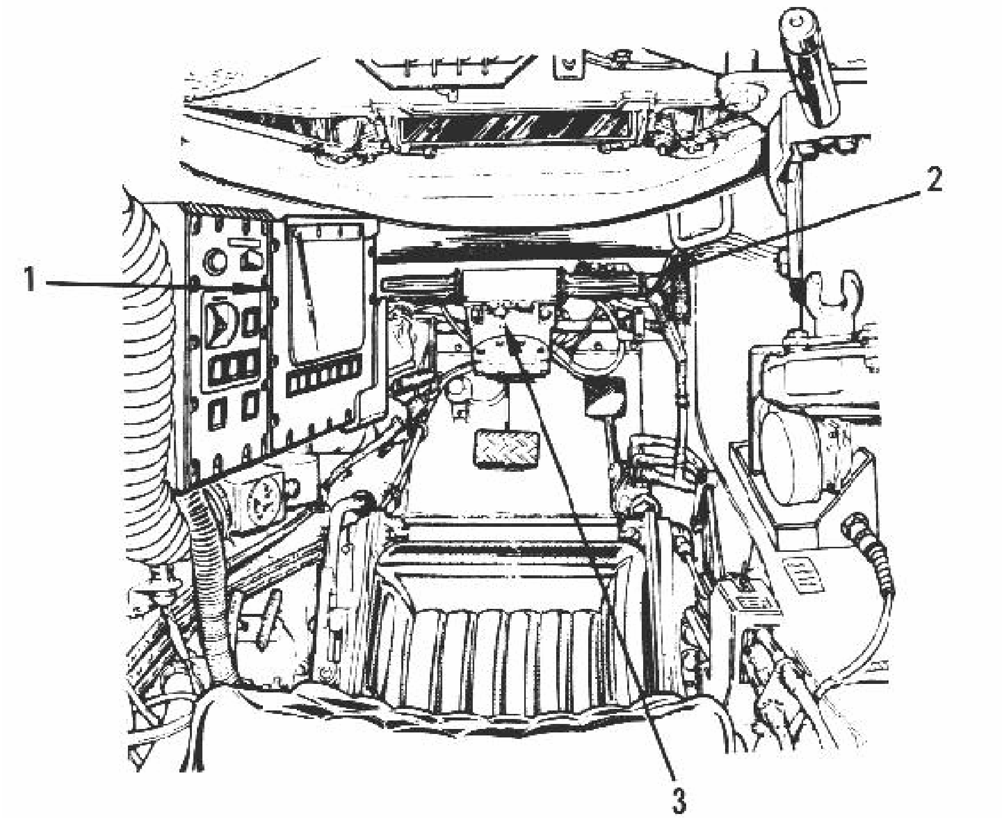
- The task had to include a complex stimulus in order to allow us to demonstrate decomposition.
- The task had to be non-sequence specific to facilitate multiple ways of accomplishing the task.
- The task had to be specific to the driver's instrument panel.

Using suitable doctrinal tasks, we demonstrate the representation of states of the selected stimuli in a data structure and demonstrate how the data structure might be populated. In terms of what we wanted to conceptually demonstrate, we considered four tasks, the power up hull system, the start engine procedure, the shut down engine procedure, and the power down hull procedure. These four tasks were selected because they met the criteria previously mentioned.

One of the benefits of this methodology is that we can create an exportable standard from the school house to any simulator. This exportable package could be distributed in the form of a context to all units to allow them to get critical feedback as to where they are in terms of the standards set by the school house. Further we suggest that there is a potential for this feedback to be shared from school house to school house. The feedback could be used to contrast and compare unit performance and identify anomalies and trends both good and bad.

Different state paths and transitions can be identified based on standing operating procedures (SOPs) and the application of tactics, techniques, and procedures (TTPs). With TTPs or SOPs you will see variations in the histograms because they are based on the artful application of doctrine. Artful application of doctrine is an important concept because this describes how different units will negotiate tactical scenarios producing different results. This exemplifies the claim we make that there is no specific set of steps that will allow a one-to-one mapping from state to a doctrinal context without applying our proposed method.

In order to place the proper scope on this problem we concentrate on the driver's instrument panel of the M1 Abrams (Figure 1). We further refine our scope by focusing on four specific procedures: the power up hull system, the start engine procedure, the shut down engine procedure, and the power down hull procedure. To summarize our concept flow the first thing we had to accomplish was to identify the doctrinal individual tasks for powering up the hull, starting and stopping a tank and powering down the hull. There are several of these steps that can be associated with a specific state. But in the context of all stimuli relevant to the driver's instrument panel, there are numerous states that can exist at any given time. We described and defined all of the stimuli in terms of a one-to-one bit relationship. After defining all of the stimuli we had to describe and define all states within the set of states. Then we developed and implemented rules to reduce the total state population through a mathematical process which represents the physical and functional limits of complex stimuli therefore reducing the set of all states to only those states we considered to be valid. Finally, given a context in the form of state-to-state statistical relationships; the valid state table and a given state, we evaluated next state probabilities and current state. In other words we were able to look at the present time and determine where we would be in terms of next state or future state.



Key	Control or Indicator	Function
1	Alert Panel	Gives the driver the first sign of any system fault or cautionary or emergency condition.
2	Steer-throttle control	Steers the tank when moved left or right as a steering bar. Twist grips control engine speed.
3	Shift control	Sets transmission to “N” (neutral), “PVT” (pivot), “R” (reverse), “D” (drive-normal forward speed range), or “L” (low forward speed range).

Figure 1. Driver’s Compartment

In addition we wanted to be able to determine probabilistically where the most likely transition will occur as a user traverses from one state to the next.

II. PROBLEM ANALYSIS

In order to better understand the problems associated with mapping simulation states to a tactical context, it is necessary to understand some common terms used throughout this thesis. In addition to understanding the following definitions, it is equally important to know that each of the following contexts is related. And as the level of abstraction increases, the ability to do a one-to-one mapping increases in difficulty. This nested relationship is illustrated in Figure 2.

Doctrine represents the fundamental principles by which the military forces or elements thereof guide their actions in support of national objectives. It is authoritative but requires judgment in application. It is a template for the artful application of combat assets against diverse threat scenarios and is often described in the form of tactics, techniques and procedures (TTP).

A *TTP* (Tactics, Techniques and Procedures) is defined as the ordered arrangement and maneuver of units in relation to each other and/or to the enemy in order to use their full potentialities. They include general and detailed methods used by troops and/or commanders to perform assigned missions and functions, specifically, the methods of using equipment and personnel. TTP's are Doctrinal recommendations that can be 'interpreted' to meet a unit or organization's specific mission requirements as the commander deems necessary as long as the final interpretation remains within doctrinal bounds. Many of these interpretations can be standardized and published as guidance to subordinate units in the form of Standard Operating Procedures (SOP).

A *Collective Task* is a clearly defined, discrete, and measurable activity, action, or event (i.e., task) which requires organized team or unit performance and leads to accomplishment of a mission or function. A collective task is derived from unit missions or higher level collective tasks. Task accomplishment requires performance of procedures composed of supporting collective or individual tasks. A collective task describes the exact performance a group must perform in the field under actual operational conditions.

A *Battle Drill* is a critical collective task performed by a platoon or smaller element without the application of a deliberate decision making process, initiated on cue, accomplished with minimal leader orders, and performed to standard throughout like units in the Army. The action is vital to success in combat or critical to preserving life. It usually involves fire or maneuver. The drill is initiated on a cue, such as an enemy action or a leader's brief order, and is a trained response to the given stimulus.

A *Crew Drill* is a critical collective task performed by a crew of a weapon or piece of equipment to use the weapon or equipment successfully in combat or to preserve life, initiated on cue, accomplished with minimal leader orders, and performed to standard throughout like units in the Army. This action is a trained response to a given stimulus, such as an enemy action, a leader's brief order, or the status of the weapon or equipment.

The *Individual Task* is the lowest behavioral level in a job or duty that is performed for its own sake. It should support a collective task and usually supports another individual task.

Here is a subset of M1A2 crew related tasks. Although not listed, Battle Drills are further distinguished into Section and Platoon drills.

A. INDIVIDUAL TASKS

Tank Commander

(1) Negotiate a route using terrain for cover and concealment.

(2) Communicate using visual signaling techniques while

mounted.

(3) React to chemical or biological hazards.

(4) Navigate while mounted.

(5) Select firing positions.

(6) Analyze terrain.

(7) Prepare/submit intelligence spot reports.

(8) Process known or suspected enemy personnel, documents, and equipment (other crew members may assist).

(9) Install the M21 metallic antitank mine.

(10) Install the M15 heavy antitank mine using an M603 fuze.

(11) Send and receive tactical reports/overlays on the commander's integrated display.

(12) Operate commander's independent thermal viewer.

Gunner

(1) Identify targets using the thermal imaging system (TIS).

(2) Recognize friendly and threat armored vehicles and aircraft

(3) Detect a target and give crew acquisition report.

Loader

(1) Communicate using visual signaling techniques while mounted.

(2) Install the M21 metallic antitank mine.

(3) Install the M15 heavy antitank mine using an M603 fuze.

(4) Recognize friendly and threat armored vehicles and aircraft.

(5) Operate SINCGARS.

(6) Load/unload 120-mm main gun.

(7) Detect a target and give a crew acquisition report.

Driver

(1) Drive an M1A2 tank.

(2) Communicate using visual signaling techniques while mounted.

(3) React to indirect fire.

(4) Detect a target and give a crew acquisition report.

B. CREW DRILLS

(1) Protect against chemical agent attack.

(2) Protect against nuclear attack.

(3) Disable and abandon an automotively crippled tank.

(4) Evacuate an injured crewman from a tank.

(5) Evacuate an injured driver from a tank.

(6) React to indirect fire.

(7) Evade an ATGM.

(8) Engage targets with multiple weapon systems.

(9) Engage a helicopter.

(10) Engage OPFOR tanks.

(11) Engage OPFOR security element.

(12) React to an ambush.

C. BATTLE DRILLS

(1) Move tactically using the wingman concept.

(2) Execute herringbone formation.

(3) Execute action drill.

(4) Execute contact drill.

(5) React to indirect fire.

(6) Execute column formation.

(7) Execute a perimeter defense.

(8) Execute wedge formation.

(9) Execute line formation.

(10) Execute bounding overwatch.

(11) Execute air attack drill.

With the exception of a limited set of Individual Tasks, there are no other tasks or drills that consist solely of M1A2 vehicle/simulator interfaces. The higher the level of doctrinal abstraction the fewer M1A2 vehicle/simulator interface directly involved if any. Therefore, from the 'user side' perspective, it is not possible to consider a one to one mapping of tasks and simulator states beyond a limited set of Individual Tasks.

The interpretive nature Doctrine also presents a significant challenge in terms of state mapping at higher levels of abstraction. The terms 'judgment' and 'operational conditions' are non-quantifiable attributes that are critical to the execution of any given task, including Individual Tasks. However, through our many experiences at the National Training Center (NTC) and Joint Readiness Training Center (JRTC), we have observed that judgment and operational conditions can be evaluated as a trend consisting of both doctrinal correctness and 'like unit' comparisons.

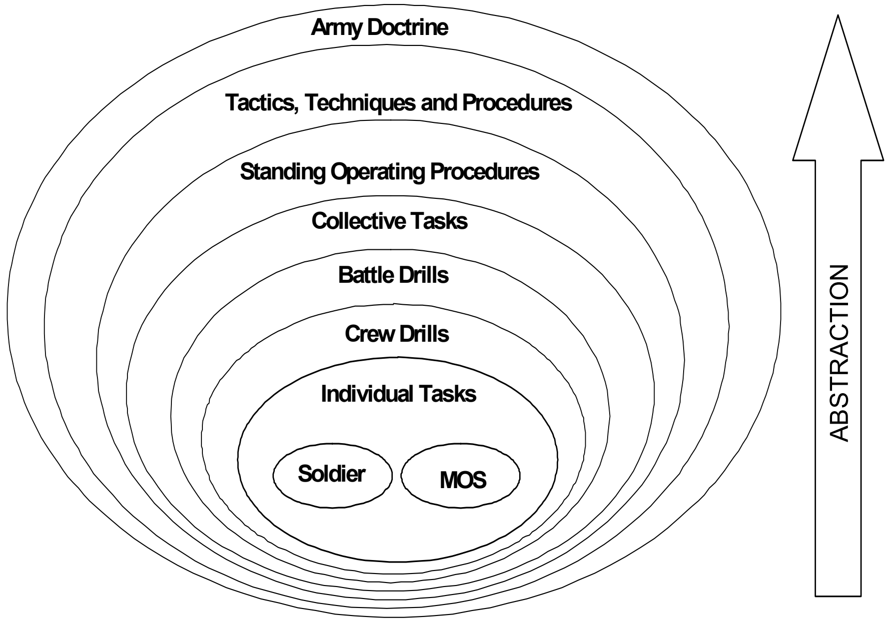


Figure 2. Doctrinal Nesting

Feedback on unit performance is normally delivered in the form of an After Action Review (AAR) conducted by an experienced and doctrinally minded Observer Controller (OC). Our training experiences with both the M1A2 and M2A2 simulators are very similar. The simulation simply replaced real vehicles with virtual vehicles but the evaluative concepts were virtually identical. Clearly the potential for evaluative feedback in the simulation environment was underdeveloped in light of its potential.

The question proposed by Dr. Saboe was "can TTP's, Collective tasks, Battle Drills and Crew Drills be mapped to specific simulation states?" In other words, can we map current state to a given doctrinal context and can we anticipate future states given a specific state and a doctrinal context. Our answer is simply "no" for one-to-one mappings beyond a limited set of Individual Tasks. However, we believe that probabilistic trending may provide a feasible solution.

To further illustrate our concept we present the following analogy.

Given a room with a finite set of suspended rings from which a monkey can traverse from one side of a room to the other and the task of traversing from one side of the room to the other, the possible paths that the monkey can take is infinite assuming that the performance standard is only to reach the other side. If a mark was left on each ring as the monkey traversed from one side of the room to the other we believe that a quantifiable pattern will begin to emerge in the form of a mean and standard deviation allowing us to evaluate the monkey's current position and anticipate his next position within the context of a given task. If the destination point were moved to a different location in the room, or a change in task, then another distinguishable pattern will emerge and so on and so forth. Thus, without knowledge of the currently assigned task, it is now possible to predict what task the monkey is executing by evaluating its current position against the established patterns of each task.

We believe that the same concept can be applied to the M1A2 simulator to evaluate state in terms of a doctrinal context. The tools necessary to accomplish this include a data structure maintaining the finite set of states and a data structure for maintaining state to state probabilities for each task.

Each task can than be nested to match the layers of doctrinal nesting as illustrated in Figure 2 thereby facilitating an evaluative feedback mechanism reflecting the most abstract levels.

Because of the flexible and dynamic nature of Army Doctrine governing the employment of the M1A2 Tank, it is not feasible to derive a one-to-one state to task mapping. However, we recommend consideration and further research of a concept that maps states to tasks through probabilities. The evaluative benefits are many. Exportability, standardization, doctrinal research and precise evaluative feedback are only a few tangible benefits that might be realized.

The 'long pole in the tent' as we see it, is the state explosion problem associated with the decomposition of complex physical and functional stimuli. However, we have proposed a possible solution where by mathematical rules define valid states thus reducing state explosion.

III. PROPOSED METHODOLOGY

Our concept illustrated in Figure 3, is designed to accommodate the interpretive and flexible nature of doctrine while providing the ability to measure or evaluate what would otherwise not be measurable. Although we may illustrate or refer to specific data structures and organizations, it is only to demonstrate the application of this concept and is no way intended to limit or validate the details of its application.

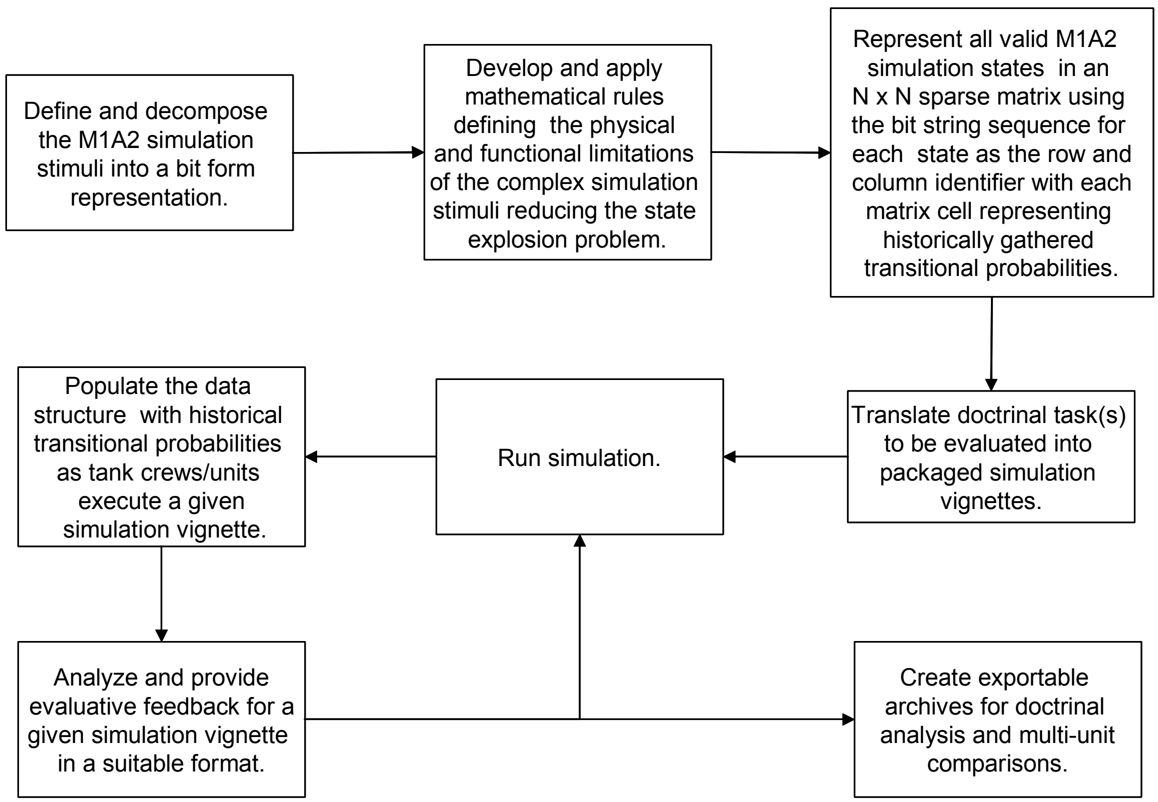


Figure 3. Concept of Proposed Method

A. STATE EXPLOSION

It was necessary for us to find an alternative solution to address the problem of deriving a one-to-one mapping from simulation states to a doctrinal context. However, as we discussed earlier one of the problems with our proposed solution is state explosion. When we decompose complex stimuli into simple stimuli the number of states grows exponentially. One of the goals of our proposed methodology is to effectively reduce state explosion. Before we can reduce state explosion we have to define and decompose M1A2 simulation stimuli and develop rules that can reduce state explosion.

1. Define and Decompose the M1A2 Driver's Instrument Panel Stimuli

There are numerous stimuli associated with the M1A2 Abrams. In order to bring the proper scope to our methodology, we concentrated on the stimuli associated with the driver's instrument panel. We further narrowed our scope to four specific procedures: the power up hull procedure, the start engine procedure, the stop engine procedure and the power down hull procedure. The driver's interface consists of two panels, the master / alert panel and the instrument panel shown in Figure 4. Both panels display simple and complex stimuli. Simple stimuli are defined as stimuli already decomposed into the most fundamental form. In other words simple stimuli can exist in one of two states, on or off. For example the night periscope switch located on the master / alert panel as illustrated in Figure 5. Complex stimuli on the other hand must be decomposed into simple stimuli because they can exist in more than two states. For example, as shown in Figure 5, the light switch located on the master / alert panel can be in any one of the following states: Blackout Lights (BO), Off, Stop Lights only, Service Lights, and Hi and Low beam.

Master / Alert Panel **Instrument Panel**

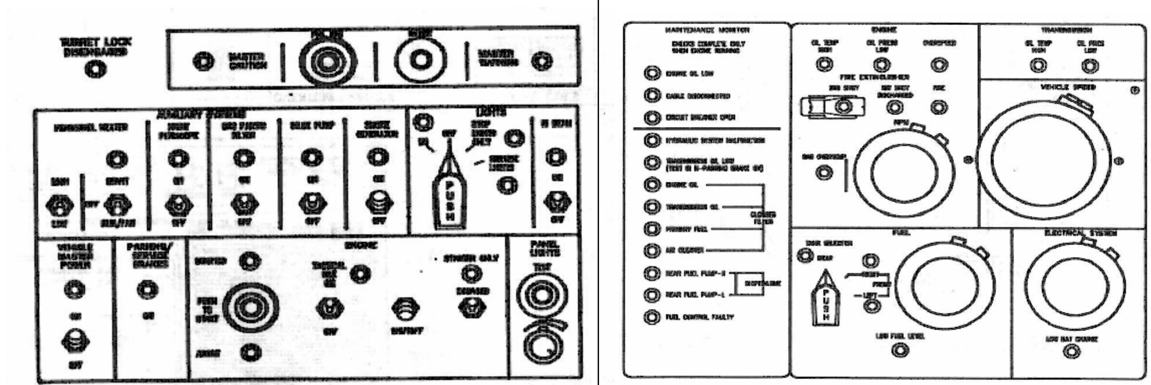


Figure 4. Master / Alert and Instrument Panel

It is necessary to decompose the stimuli associated with the driver's instrument panel into simple stimuli because we want to represent the stimuli in bit form to facilitate probabilistic trending.

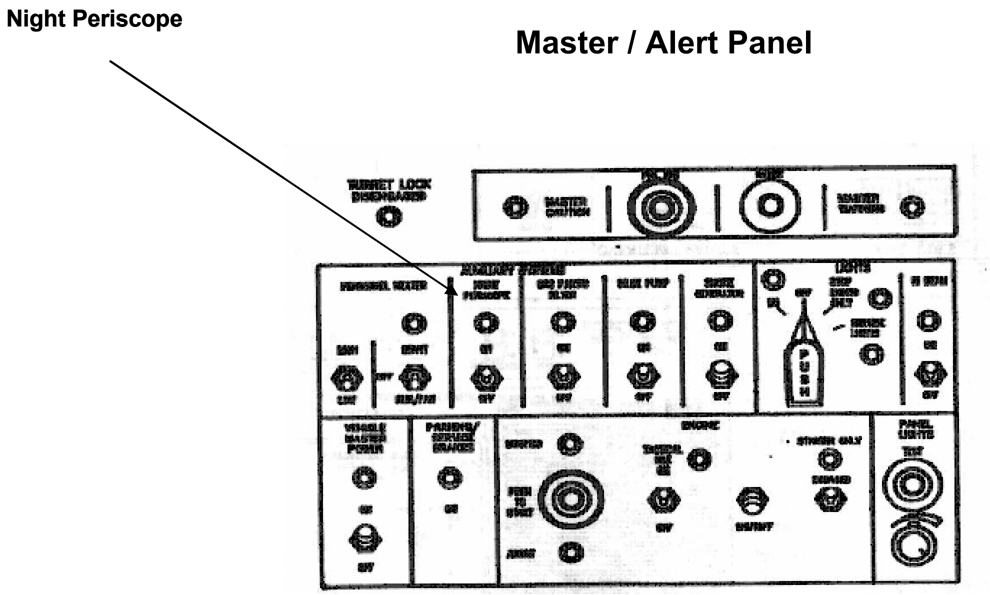


Figure 5. Night Periscope

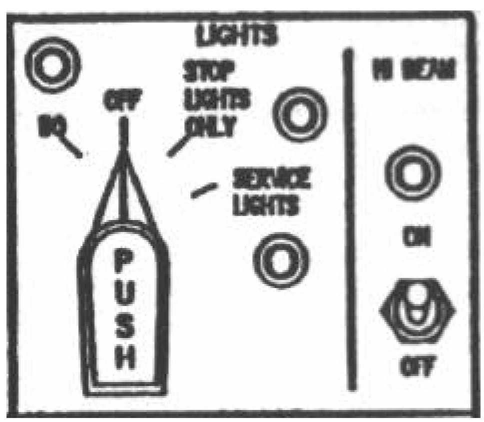


Figure 6. Light Switch Panel

a. Definition of M1A2 Driver's Instrument Panel Stimuli

We need to define the stimuli used in our concept in order to better understand the state explosion problem. Our efforts in developing this methodology were focused on the doctrinal steps relevant to the four procedures, mentioned earlier.

All of these procedures are executed by the M1A2 driver. There are specific stimuli associated with each procedure and it is with this set of particular stimuli we demonstrate our methodology. Although there are numerous stimuli associated with these four procedures we only consider the stimuli associated with switches and not lights. In other words all switches or buttons manipulated by the driver relevant to the previously mentioned procedures are considered. Taking this into consideration we determined that there are 13 stimuli relevant to the execution of our methodology (Table 1) note that the master power switch is used in two different procedures, but only counted once in the total number of relevant stimuli. Now that the relevant stimuli have been identified the next step is to decompose the stimuli into bit form.

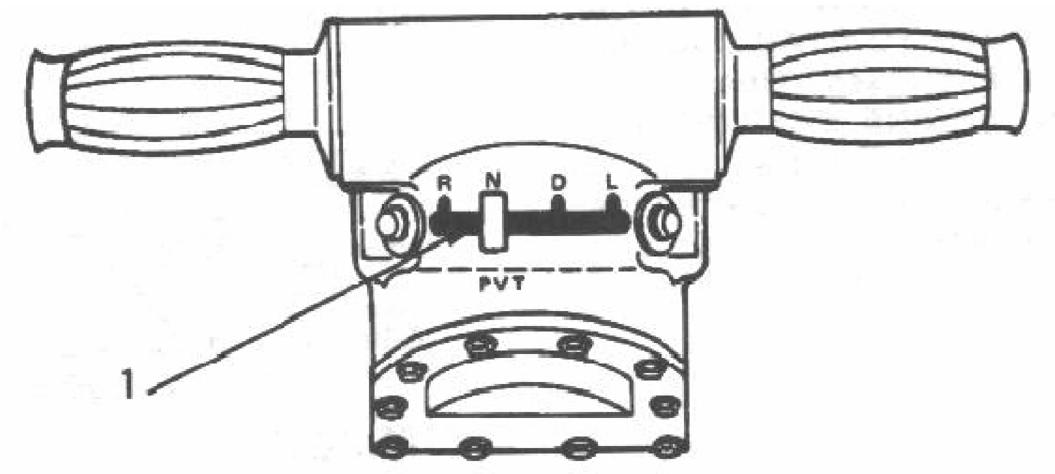
Procedure	Stimuli	# of States	Actual Name	Function
A				
POWER UP	1. Set dome light to off position	2	Dome Light	Self explanitory
HULL SYSTEM	2. Pull out and set vehicle master power	2	Master Power	Connects batteries/alternator to the
	switch to on		Push Button	tank indicates poweris on
	3. Push and hold panel light test push-	2	Panel Lights	Test the operation of lights and
	button. Ensure all panel lights are in			adjust the brightness of the lights
	operation			
	4. Depress reset push-button on	2	Reset Button	Reset the current state of the
	driver's alert panel			indicators
B				
START ENGINE	1. Make sure shift control is set to "N"	5	Shift Control	Sets transmission to N, R, D, L, or PVT
	2. Press and hold push to start button	2	Push to Start	Allows the driver to initiate engine start
	no longer than 1 second and let go			sequence
C				
SHUT DOWN ENGINE	1. Press and hold service brake pedal	2	Service Brake	Controls hydraulic operation of breakes
	to stop the tank		Pedal	in transmission
	2. Press parking brake pedal all the way	2	Parking Brake	Operates the brakes in the
	and then let go		Pedal	transmission
	3. Pull out and set engine shut off switch	2	Engine Shut Off	Sends signal to DECU to initiate engine
	down to shutoff and then let go			shutoff sequence
D				
POWER DOWN	*1. Pull out and set and hold vehicle master power	2	Master Power	Connects batteries/alternator to the
HULL SYSTEM	switch to off for 1 second		Push Button	tank indicates power is on

*** Repeated procedure**

Table 1. Relevant Stimuli

b. ***Decomposition of M1A2 Driver's Instrument Panel Stimuli Into Bit Form***

It is only necessary to decompose complex stimuli. As explained earlier, simple stimuli can not be decomposed any further. Table 1 list all of the simple stimuli related to the four procedures we consider in our methodology. As listed in Table 1 and illustrated in Figure 7 the shift control has five positions, this is a complex stimulus and requires decomposition.



1 - Shift Control Selector

Figure 7. Shift Control

It is difficult to represent the shift control in bit form as it is currently presented so each position on the shift control must be translated to bit form. Figure 8 illustrates the process of decomposing the complex stimulus into a simple stimulus. It is very apparent that the decomposition of complex stimuli creates state explosion. The shift control stimulus went from five states before decomposition, to ten states after decomposition. However, the shift control is now decomposed into a simple stimulus with ten states thus facilitating the process of translating all of the relevant stimuli into a bit string that can be represented by a simulator. Each position of the shift control can now either be in an engaged state, represented by a one or a disengaged state represented by a zero.

This is the desired form for all stimuli. We determined that with 13 simple stimuli we can produce a total of 8192 states ($2^{13} = 8192$). The total number of states includes both relevant and irrelevant states.

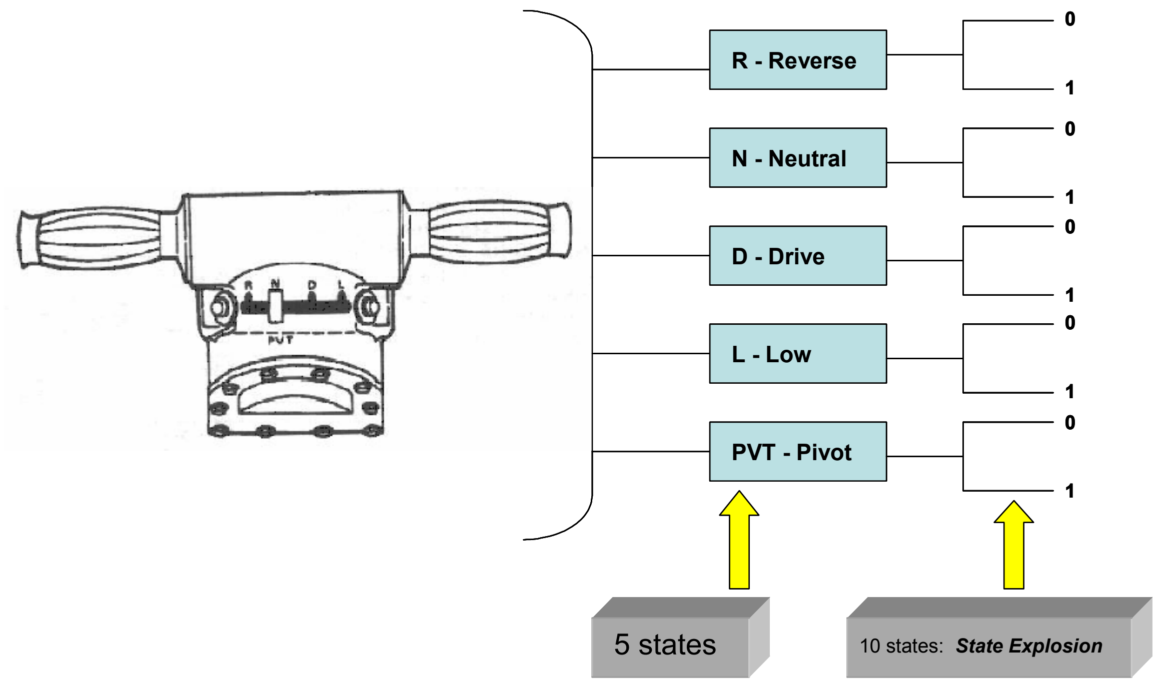


Figure 8. Decomposition of Complex Stimulus

Once we have decomposed all of the stimuli into simple form, we can eliminate all irrelevant states. When we remove all irrelevant states from the set of all possible states, only valid states remain. Table 2 illustrates a portion of the state table generated after all of the states have been decomposed. The rows represent the states and the columns represent the stimuli. For example row 1 represents a state in which all of the stimuli are in the off position. Row 27 represents a state in which all of the stimuli are in the off position except for the engine shut off and the service brake. Notice that row 8192 is an irrelevant state because although it is possible to have stimuli 1 – 4 and 12 – 13 represent an "on" state, it is impossible for stimuli 5 – 11 to represent an "on" state simultaneously, because the selector switch can only be in one position at a time.

In other words the tank can either be in drive or neutral or reverse or low or pivot. Likewise it is possible to engage the start button and the engine shut off button at the same time but it is an unlikely state.

STIMULI

STATES	Dome Light	Master Pwr	Panel Lights	Reset Button	Neutral	Drive	Reverse	Low	Pivot	Eng Shut Off	Start Button	Service Brk	Parking Brk
1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	1
3	0	0	0	0	0	0	0	0	0	0	0	1	0
4	0	0	0	0	0	0	0	0	0	0	0	0	1
5	0	0	0	0	0	0	0	0	0	0	1	0	0
6	0	0	0	0	0	0	0	0	0	0	0	1	1
7	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	1
9	0	0	0	0	0	0	0	0	0	1	0	1	0
10	0	0	0	0	0	0	0	0	0	0	1	0	1
11	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	1	1
13	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	1
15	0	0	0	0	0	0	0	0	0	0	1	1	0
16	0	0	0	0	0	0	0	0	0	0	0	0	1
17	0	0	0	0	0	0	0	0	1	0	0	0	0
18	0	0	0	0	0	0	0	0	0	1	0	1	1
19	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	1	0	1
21	0	0	0	0	0	0	0	0	0	0	0	1	0
22	0	0	0	0	0	0	0	0	0	0	0	0	1
23	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	1	1
25	0	0	0	0	0	0	0	0	0	0	1	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	1
27	0	0	0	0	0	0	0	0	0	1	0	1	0
	0	0	0	0	0	0	0	0	0	0	0	0	1
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
8192	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 2. State Table

Now that we have a state table that represents all of the possible states generated by 13 stimuli we have to reduce it. Reducing the state table means eliminating all irrelevant states from the table. It is necessary to remove the irrelevant states because they represent states that either would not or could not take place. In order to reduce the state table we developed mathematical rules that must be applied to all of the possible states. We propose that by applying these rules we can eliminate the irrelevant states.

2. Develop and Apply Mathematical Rules to Reduce State Explosion

At this point the state table has been created and populated with all of the possible states generated by the thirteen stimuli relevant to four distinct procedures. The issue we are confronted with is our state table contains both relevant and irrelevant states. Our primary goal at this point is to eliminate the irrelevant states from the state table with only relevant states remaining. This is defined as reducing state explosion. The proposed method for accomplishing this task is developing and applying mathematical rules to eliminate all states that can not exist due to the physical or functional limitations of the stimuli.

a. Development of Mathematical Rules

By using the "*exclusive or*" logical operation we determined that any one of the simple stimuli we have defined can only exist in one of two states. It would be physically impossible for any one of the simple stimuli to exist in more than one state at a time. In this case the stimuli are either on or off, or engaged or disengaged. The rules we derived are based on the physical limitations of the stimuli. For example the shift control has five positions: neutral, drive, low, reverse, and pivot. And we know from previous discussions that the shift control can only be in one of these positions at a time, therefore we can say that the shift control can be in drive, or neutral, or reverse, or low or pivot, but not drive and pivot or any other similar combination. Using this concept we generated Table 3. We expect that the application of some of the rules will not significantly reduce the state table because they can exist in one and only one state. For example regardless if the dome light is on or off, it is still valid to engage the panel light test button. Both stimuli can exist simultaneously in any state because each are physically limited to one of two states, on or off. In addition they are physically and functionally separate stimuli. Unlike the simple stimuli we expect a significant reduction in the state table when we apply any rule affecting complex stimuli.

Although the rules associated with simple stimuli are implied, we demonstrate their application for the purpose of showing the effect simple stimuli have on the state table. It is worth mentioning that there is no significant change in the state table when rules associated with simple stimuli are applied.

STIMULI	RULE	DEFINITION	APPLICATION
Dome Light	dome_light_on ⊕ dome_light _off	The dome light can either be on or off.	Applying this rule would not yield any significant reduction in the state table.
Master Power Switch	mps_on ⊕ mps_off	The master power switch is either on or off.	Applying this rule would not yield any significant reduction in the state table.
Panel Light test	pl_test_on ⊕ pl_test_off	The panel light test button is engaged or disengaged.	Applying this rule would not yield any significant reduction in the state table.
Reset Button	reset_button_on ⊕ reset_button_off	The reset button is engaged or disengaged.	Applying this rule would not yield any significant reduction in the state table.
Shift Control	shift_cntrl_N ⊕ shift_cntrl_R ⊕ shift_cntl_D ⊕ shift_cntrl_L ⊕ shift_cntrl_PVT	The shift control can either be in drive or reverse, or nuetral or low or pivot.	Applying this rule would yield a significant reduction in the state table.
Pust to Start	start_button_on ⊕ start_button_off	The start button is either pressed or not pressed	Applying this rule would not yield any significant reduction in the state table.
Service Brake	srv_brk_engaged ⊕ srv_brk_disengaged	The service brake either engaged or disengaged	Applying this rule would not yield any significant reduction in the state table.
Parking Brake	prk_brk_engaged ⊕ prk_brk_disengaged	The parking brake either engaged or disengaged	Applying this rule would not yield any significant reduction in the state table.
Engine Shut Off	eng_shutoff_on ⊕ eng_shutoff_off	The engine shutoff is either engaged or disengaged	Applying this rule would not yield any significant reduction in the state table.

Table 3. Rules

Rules applied to complex stimuli produce significant results in the state table because the state of any complex stimuli is true or valid when exactly one state of a complex stimulus is true. In other words, because of the nature of a complex stimulus there is only going to be one valid state. To further illustrate this point Figure 9 depicts the shift control selector which was previously identified as a complex stimulus. The selector can only be in one position or state at a time. It is physically impossible for the selector to exist in more than one position at a time.

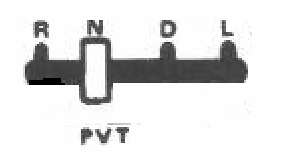


Figure 9. Shift Control Selector

b. Application of Mathematical Rules to Reduce State Explosion

Now that the rules have been defined we can apply them to the state table in order to eliminate irrelevant states. As previously mentioned, an irrelevant state is a state that can not exist. And we have identified that because of the decomposition of complex stimuli, irrelevant states are represented in the state table. The applicable mathematical rule used to reduce the state table is the *exclusive or* operation. By definition (Table 4), the exclusive or operation eliminates all states which do not satisfy the condition that one and only one state is true for complex stimuli, since it is possible to represent a state in which a complex stimulus occupies more than one state.

State 1	State 2	State 1 $\oplus$ State 2
0	0	0
0	1	1
1	0	1
1	1	0

Table 4. Truth Table

We use the truth table to emphasize two points. The first point is that there has to be an existing state. This means that any state in which a complex stimulus is represented by all zeros is an irrelevant state. The second point is that one and only one state can exist for a complex stimulus. To put it in the simplest terms, if the value one is represented in the third column of the truth table, the state is valid. By introducing the exclusive or operation we can reasonably expect to identify and eliminate all of the irrelevant states from the state table. When considering complex stimuli, observe that there are five positions or states in which the shift control can exist. However, the applicable rule states that the shift control can only be in one of these positions at a time. To demonstrate how the rules are applied to reduce the state explosion we use only a portion of the state table we generated, illustrated in Table 5.

Dome Light	Master Pwr	Panel Lights	Reset Button	Neutral	Drive	Reverse	Low	Pivot	Eng Shut Off	Start Button	Service Brk	Parking Brk
1	1	1	1	1	1	1	0	1	1	1	0	1
1	1	1	1	1	1	1	0	1	1	1	1	0
1	1	1	1	1	1	1	0	1	1	1	1	1
1	1	1	1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	1	1	1	0	0	0	0	1
1	1	1	1	1	1	1	1	0	0	0	1	0
1	1	1	1	1	1	1	1	0	0	0	1	1
1	1	1	1	1	1	1	1	0	0	1	0	0
1	1	1	1	1	1	1	1	0	0	1	0	1
1	1	1	1	1	1	1	1	0	0	1	1	0
1	1	1	1	1	1	1	1	0	0	1	1	1
1	1	1	1	1	1	1	1	0	1	0	0	0
1	1	1	1	1	1	1	1	0	1	0	0	1
1	1	1	1	1	1	1	1	0	1	0	1	0
1	1	1	1	1	1	1	1	0	1	0	1	1
1	1	1	1	1	1	1	1	0	1	1	0	0
1	1	1	1	1	1	1	1	0	1	1	0	1
1	1	1	1	1	1	1	1	0	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	0	0	0	0
1	1	1	1	1	1	1	1	1	0	0	0	1
1	1	1	1	1	1	1	1	1	0	0	1	0
1	1	1	1	1	1	1	1	1	0	0	1	1
1	1	1	1	1	1	1	1	1	0	1	0	0
1	1	1	1	1	1	1	1	1	0	1	0	1
1	1	1	1	1	1	1	1	1	0	1	1	0
1	1	1	1	1	1	1	1	1	0	1	1	1
1	1	1	1	1	1	1	1	1	1	0	0	0
1	1	1	1	1	1	1	1	1	1	0	0	1
1	1	1	1	1	1	1	1	1	1	0	1	0
1	1	1	1	1	1	1	1	1	1	0	1	1
1	1	1	1	1	1	1	1	1	1	1	0	0
1	1	1	1	1	1	1	1	1	1	1	0	1
1	1	1	1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1

Table 5. State Table (states 8157-8192)

For demonstration purposes we introduce a rule associated with simple stimuli at this point. The rule we introduce is rule 1 listed in Table 5 as:

$$\text{dome\_light\_on} \oplus \text{dome\_light\_off}$$

As you can see this stimuli exist in one of two states, “on” or “off”.

This rule expresses that the dome light is either on or off. Now we identify the states where the dome light is on and off at the same time and eliminate them because the physical limits of this stimulus make the existence of this state impossible. The result of applying this rule is that no states eliminated. As discussed previously with simple stimuli we can expect that there would be no significant change in the state table by applying rules relating to simple stimuli because the physical limitations of the stimuli will not allow it to exist in more than one state at a time, therefore wherever the dome light is represented as a 1 bit or a 0 bit, that state is valid for the applied rule. Figure 10 illustrates this point. We suggest that by applying rules related to simple stimuli, such as the panel light test or the master power switch, we get the same results from the state table, no change. It is with the application of the rules to complex stimuli we observe significant reduction in the state table; this is the main reason we develop the rules associated with complex stimuli. As previously stated, complex stimuli can only exist in one and only one state at a time. We suggest that by applying the appropriate rule or rules, states containing complex stimuli existing in more than one state at a time, are eliminated from the state table. Figures 11 - 13 illustrates how this would work.

1. The rule is applied in order to reduce the state table

dome_light_on ⊕ dome_light_off

2. The state table is searched for violations of this rule

Dome Light	aster Pwr	Panel Lights	Reset Button	Neutral	Drive	Reverse	Low	Pivot	Eng Shut Off	Start Button	Service Brk	Parking Brk
1	1	1	1	1	1	1	0	1	1	1	0	1
1	1	1	1	1	1	1	0	1	1	1	1	0
1	1	1	1	1	1	1	0	1	1	1	1	1
1	1	1	1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	1	1	1	0	0	0	0	1
1	1	1	1	1	1	1	1	0	0	0	1	0
1	1	1	1	1	1	1	1	0	0	0	1	1
1	1	1	1	1	1	1	1	0	0	1	0	0
1	1	1	1	1	1	1	1	0	0	1	0	1
1	1	1	1	1	1	1	1	0	0	1	1	0
1	1	1	1	1	1	1	1	0	0	1	1	1
1	1	1	1	1	1	1	1	0	1	0	0	0
1	1	1	1	1	1	1	1	0	1	0	0	1
1	1	1	1	1	1	1	1	0	1	0	1	0
1	1	1	1	1	1	1	1	0	1	0	1	1
1	1	1	1	1	1	1	1	0	1	1	0	0
1	1	1	1	1	1	1	1	0	1	1	0	1
1	1	1	1	1	1	1	1	0	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	0	0	0	0
1	1	1	1	1	1	1	1	1	0	0	0	1
1	1	1	1	1	1	1	1	1	0	0	1	0
1	1	1	1	1	1	1	1	1	0	0	1	1
1	1	1	1	1	1	1	1	1	0	1	0	0
1	1	1	1	1	1	1	1	1	0	1	0	1
1	1	1	1	1	1	1	1	1	0	1	1	0
1	1	1	1	1	1	1	1	1	0	1	1	1
1	1	1	1	1	1	1	1	1	1	0	0	0
1	1	1	1	1	1	1	1	1	1	0	0	1
1	1	1	1	1	1	1	1	1	1	0	1	0
1	1	1	1	1	1	1	1	1	1	0	1	1
1	1	1	1	1	1	1	1	1	1	1	0	0
1	1	1	1	1	1	1	1	1	1	1	0	1
1	1	1	1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1

3. No change in the table. All of the states are valid for this rule.

Dome Light	Master Pwr	Panel Lights	Reset Button	Neutral	Drive	Reverse	Low	Pivot	Eng Shut Off	Start Button	Service Brk	Parking Brk
1	1	1	1	1	1	1	0	1	1	1	0	1
1	1	1	1	1	1	1	0	1	1	1	1	0
1	1	1	1	1	1	1	0	1	1	1	1	1
1	1	1	1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	1	1	1	0	0	0	0	1
1	1	1	1	1	1	1	1	0	0	0	1	0
1	1	1	1	1	1	1	1	0	0	0	1	1
1	1	1	1	1	1	1	1	0	0	1	0	0
1	1	1	1	1	1	1	1	0	0	1	0	1
1	1	1	1	1	1	1	1	0	0	1	1	0
1	1	1	1	1	1	1	1	0	0	1	1	1
1	1	1	1	1	1	1	1	0	1	0	0	0
1	1	1	1	1	1	1	1	0	1	0	0	1
1	1	1	1	1	1	1	1	0	1	0	1	0
1	1	1	1	1	1	1	1	0	1	0	1	1
1	1	1	1	1	1	1	1	0	1	1	0	0
1	1	1	1	1	1	1	1	0	1	1	0	1
1	1	1	1	1	1	1	1	0	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	0	0	0	0
1	1	1	1	1	1	1	1	1	0	0	0	1
1	1	1	1	1	1	1	1	1	0	0	1	0
1	1	1	1	1	1	1	1	1	0	0	1	1
1	1	1	1	1	1	1	1	1	0	1	0	0
1	1	1	1	1	1	1	1	1	0	1	0	1
1	1	1	1	1	1	1	1	1	0	1	1	0
1	1	1	1	1	1	1	1	1	0	1	1	1
1	1	1	1	1	1	1	1	1	1	0	0	0
1	1	1	1	1	1	1	1	1	1	0	0	1
1	1	1	1	1	1	1	1	1	1	0	1	0
1	1	1	1	1	1	1	1	1	1	0	1	1
1	1	1	1	1	1	1	1	1	1	1	0	0
1	1	1	1	1	1	1	1	1	1	1	0	1
1	1	1	1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 10. Application of Rule 1

shift_cntrl_R ⊕ shift_cntrl_N ⊕ shift_cntrl_D ⊕ shift_cntrl_L⊕ shift_cntrl_PVT

1. We apply the shift control rule (Rule # 5). This rule is related to a complex stimuli, therefore it Is reasonable to expect a significant change in the table

Dome Light	Master Pwr	Panel Lights	Reset Button	Neutral	Drive	Reverse	Low	Pivot	Eng Shut Off	Start Button	Service Brk	Parking Brk
1	1	1	1	1	1	1	0	1	1	1	0	1
1	1	1	1	1	1	1	0	1	1	1	1	0
1	1	1	1	1	1	1	0	1	1	1	1	1
1	1	1	1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	1	1	1	0	0	0	0	1
1	1	1	1	1	1	1	1	0	0	0	1	0
1	1	1	1	1	1	1	1	0	0	0	1	1
1	1	1	1	1	1	1	1	0	0	1	0	0
1	1	1	1	1	1	1	1	0	0	1	0	1
1	1	1	1	1	1	1	1	0	0	1	1	0
1	1	1	1	1	1	1	1	0	0	1	1	1
1	1	1	1	1	1	1	1	0	1	0	0	0
1	1	1	1	1	1	1	1	0	1	0	0	1
1	1	1	1	1	1	1	1	0	1	0	1	0
1	1	1	1	1	1	1	1	0	1	0	1	1
1	1	1	1	1	1	1	1	0	1	1	0	0
1	1	1	1	1	1	1	1	0	1	1	0	1
1	1	1	1	1	1	1	1	0	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	0	0	0	0
1	1	1	1	1	1	1	1	1	0	0	0	1
1	1	1	1	1	1	1	1	1	0	0	1	0
1	1	1	1	1	1	1	1	1	0	0	1	1
1	1	1	1	1	1	1	1	1	0	1	0	0
1	1	1	1	1	1	1	1	1	0	1	0	1
1	1	1	1	1	1	1	1	1	0	1	1	0
1	1	1	1	1	1	1	1	1	0	1	1	1
1	1	1	1	1	1	1	1	1	1	0	0	0
1	1	1	1	1	1	1	1	1	1	0	0	1
1	1	1	1	1	1	1	1	1	1	0	1	0
1	1	1	1	1	1	1	1	1	1	0	1	1
1	1	1	1	1	1	1	1	1	1	1	0	0
1	1	1	1	1	1	1	1	1	1	1	0	1
1	1	1	1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 11. Application of the Rule

2. The entire table is searched for violations of rule #2. Any state representing the shift control occupying more than one position at a time (indicated by a 1) is eliminated.

Dome Light	Master Pwr	Panel Lights	Reset Button	Neutral	Drive	Reverse	Low	Pivot	Eng Shut Off	Start Button	Service Brk	Parking Brk
1	1	1	1	1	1	1	0	1	1	1	0	1
1	1	1	1	1	1	1	0	1	1	1	1	0
1	1	1	1	1	1	1	0	1	1	1	1	1
1	1	1	1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	1	1	1	0	0	0	0	1
1	1	1	1	1	1	1	1	0	0	0	1	0
1	1	1	1	1	1	1	1	0	0	0	1	1
1	1	1	1	1	1	1	1	0	0	1	0	0
1	1	1	1	1	1	1	1	0	0	1	0	1
1	1	1	1	1	1	1	1	0	0	1	1	0
1	1	1	1	1	1	1	1	0	0	1	1	1
1	1	1	1	1	1	1	1	0	1	0	0	0
1	1	1	1	1	1	1	1	0	1	0	0	1
1	1	1	1	1	1	1	1	0	1	0	1	0
1	1	1	1	1	1	1	1	0	1	0	1	1
1	1	1	1	1	1	1	1	0	1	1	0	0
1	1	1	1	1	1	1	1	0	1	1	0	1
1	1	1	1	1	1	1	1	0	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	0	0	0	0
1	1	1	1	1	1	1	1	1	0	0	0	1
1	1	1	1	1	1	1	1	1	0	0	1	0
1	1	1	1	1	1	1	1	1	0	0	1	1
1	1	1	1	1	1	1	1	1	0	1	0	0
1	1	1	1	1	1	1	1	1	0	1	0	1
1	1	1	1	1	1	1	1	1	0	1	1	0
1	1	1	1	1	1	1	1	1	0	1	1	1
1	1	1	1	1	1	1	1	1	1	0	0	0
1	1	1	1	1	1	1	1	1	1	0	0	1
1	1	1	1	1	1	1	1	1	1	0	1	0
1	1	1	1	1	1	1	1	1	1	0	1	1
1	1	1	1	1	1	1	1	1	1	1	0	0
1	1	1	1	1	1	1	1	1	1	1	0	1
1	1	1	1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 12. Table search

3. The results of the application of this rule is the state table is reduced.

Dome Light	Master Pwr	Panel Lights	Reset Button	Neutral	Drive	Reverse	Low	Pivot	Eng Shut Off	Start Button	Service Brk	Parking Brk
1	1	1	1	1	1	1	0	1	1	1	0	1
1	1	1	1	1	1	1	0	1	1	1	1	0
1	1	1	1	1	1	1	0	1	1	1	1	1
1	1	1	1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	1	1	1	0	0	0	0	1
1	1	1	1	1	1	1	1	0	0	0	1	0
1	1	1	1	1	1	1	1	0	0	0	1	1
1	1	1	1	1	1	1	1	0	0	1	0	0
1	1	1	1	1	1	1	1	0	0	1	0	1
1	1	1	1	1	1	1	1	0	0	1	1	0
1	1	1	1	1	1	1	1	0	0	1	1	1
1	1	1	1	1	1	1	1	0	1	0	0	0
1	1	1	1	1	1	1	1	0	1	0	0	1
1	1	1	1	1	1	1	1	0	1	0	1	0
1	1	1	1	1	1	1	1	0	1	0	1	1
1	1	1	1	1	1	1	1	0	1	1	0	0
1	1	1	1	1	1	1	1	0	1	1	0	1
1	1	1	1	1	1	1	1	0	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	0	0	0	0
1	1	1	1	1	1	1	1	1	0	0	0	1
1	1	1	1	1	1	1	1	1	0	0	1	0
1	1	1	1	1	1	1	1	1	0	0	1	1
1	1	1	1	1	1	1	1	1	0	1	0	0
1	1	1	1	1	1	1	1	1	0	1	0	1
1	1	1	1	1	1	1	1	1	0	1	1	0
1	1	1	1	1	1	1	1	1	0	1	1	1
1	1	1	1	1	1	1	1	1	1	0	0	0
1	1	1	1	1	1	1	1	1	1	0	0	1
1	1	1	1	1	1	1	1	1	1	0	1	0
1	1	1	1	1	1	1	1	1	1	0	1	1
1	1	1	1	1	1	1	1	1	1	1	0	0
1	1	1	1	1	1	1	1	1	1	1	0	1
1	1	1	1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1

This portion of the state table is eliminated.

Figure 13. Eliminate irrelevant states

It is important to note that Figure 13 represents only a portion of the entire state table. This portion of the table was completely eliminated by rule #5. If the entire table was displayed, the table would reveal that other portions of the table were eliminated as well. It is reasonable to expect that after all of the rules have been applied only relevant states remain. As we have demonstrated with a portion of the state table developing and applying mathematical rules that define the physical and functional limitations of complex stimuli reduces the state table.

B. CONCEPT OF METHODOLOGY

The focus for this portion of discussion will be limited to a small subset of the M1A2 simulator stimuli associated with the MOS specific task of powering up an M1A2 hull system. The task of 'POWER UP HULL SYSTEM' as extracted from TM 9-2350-264-10-1 and taught at the Armor School in Ft. Knox Kentucky is as follows:

1. Power Up Hull System

A. Make sure all switches on driver's master panel are off.

B. Make sure the following conditions on driver's instrument panel are ok :

1. Tank Selector Switch is set to the rear.
2. Fire Extinguisher 2ND Shot red cover is closed.
3. All gages show lowest (left) position.

C. Set dome light to off position.

D. Pull out and set vehicle master power switch to on.

E. Check hull networks box.

F. Check power distribution box.

G. Check that the following lights are not lit:

Personnel Heater, Night Periscope, Bilge Pump, Smoke Generator, and Hi Beam.

H. Check that red parking/service brake light on driver's master panel and master warning light on driver's alert panel are lit.

I. Push and hold panel light test push-button. Ensure all panel lights are in operation.

J. Depress reset push-button on driver's alert panel.

K. Adjust brightness of lights on driver's master panel and driver's instrument panel.

L. Adjust brightness of lights on driver's alert panel.

M. Look at electrical system voltmeter gage:

    1. Needle should show 23 to 29 volts (green band).

N. Check that the cable disconnect light is not lit.

O. Check that circuit breaker open light is not lit.

P. Check all fuel levels and report to Tank Commander.

Q. Check hydraulic pressure gauge:

    1. Normal reading is 1200-1800 psi (green band).

We set the conditions in that the dome light is 'on' upon entering the driver's compartment and the remaining switches are in the correct power up configuration prior to the task being performed, leaving only 4 of the 16 steps that involve the driver changing the state of the drivers compartment (C, D, I and K) in order to correctly accomplish this task. The specific stimuli associated with steps C, D, I and K include the Dome Light, Master Power, Panel Test, and Reset switches. We will limit our example to those 4 switches thus giving us a set of 16 possible states as shown in Table 6.

STATES	Dome Light	Master Power	Panel Test	Reset
1	0	0	0	0
2	0	0	0	1
3	0	0	1	0
4	0	0	1	1
5	0	1	0	0
6	0	1	0	1
7	0	1	1	0
8	0	1	1	1
9	1	0	0	0
10	1	0	0	1
11	1	0	1	0
12	1	0	1	1
13	1	1	0	0
14	1	1	0	1
15	1	1	1	0
16	1	1	1	1

SWITCHES

Table 6. Switch / State

The set of valid states must then be arranged in an N x N data structure that will be used to maintain the transitional weights from one state to another. In our example we use a 16 x 16 sparse matrix with the rows representing current state and columns representing future states Figure 14. One of the many benefits of the sparse matrix is that only those states that demonstrate transitional relationships will maintain data therefore minimizing the overall size of the data structure. We have also opted to use the bit string sequence of each represented state as the row and column identifiers to facilitate the use of binary operations. Most simulation scenarios are already created to provide the conditions to complete specific doctrinally derived requirements in the form of task and standard. Most Army training and evaluative environments, outside of simulation, have conditions that are standardized to facilitate the focused training and evaluation of selected tasks. Large deviations in conditions will generally result in large deviations from a given doctrinal template. The same will apply in our concept. If a task is executed in an M1A2 simulator under varying conditions, the chains of state transitions will also vary resulting in a wider margin or deviation from an established mean.

NEXT STATE

CURRENT STATE

	0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111
0000																
0001																
0010																
0011																
0100																
0101																
0110																
0111																
1000																
1001																
1010																
1011																
1100																
1101																
1110																
1111																

Figure 14. Current / Future State Sparse Matrix

In our example we established the condition by stating that the dome light is initially 'on' and all other switches are in the correct power up configuration to facilitate the measured evaluation of the POWER UP HULL SYSTEM task. Populating the data structure, or sparse matrix in our example, is the mechanism for recording the weighted transitional probabilities from one state to another for a given task and conditions. In our example we choose to use an incremental weighting system as each state is visited. We will consider 3 notional drivers who will execute the MOS specific task of POWER UP HULL SYSTEM. The first and second driver's transitions are identical whereas the third driver varies from the sequence of the steps taken by drivers 1 and 2. The resulting transitions and data entries into the sparse matrix for driver 1 and 2 are as follows:

Drivers 1 and 2

<u>Transitions</u>

S. Starting state

SWITCHES

	Dome Light	Master Power	Panel Test	Reset
State	1	0	0	0

C. Set dome light to off position.

SWITCHES

	Dome Light	Master Power	Panel Test	Reset
State	0	0	0	0

D. Pull out and set vehicle master power switch to on.

SWITCHES

	Dome Light	Master Power	Panel Test	Reset
State	0	1	0	0

I. Push and hold panel light test push-button.

SWITCHES

	Dome Light	Master Power	Panel Test	Reset
State	0	1	1	0

I1. Releases panel light test push-button after checks are complete.

SWITCHES

	Dome Light	Master Power	Panel Test	Reset
State	0	1	0	0

J. Depress reset push-button on driver's alert panel.

SWITCHES

	Dome Light	Master Power	Panel Test	Reset
State	0	1	0	1

J1. Releases reset push-button.

	SWITCHES			
	Dome Light	Master Power	Panel Test	Reset
State	0	1	0	0

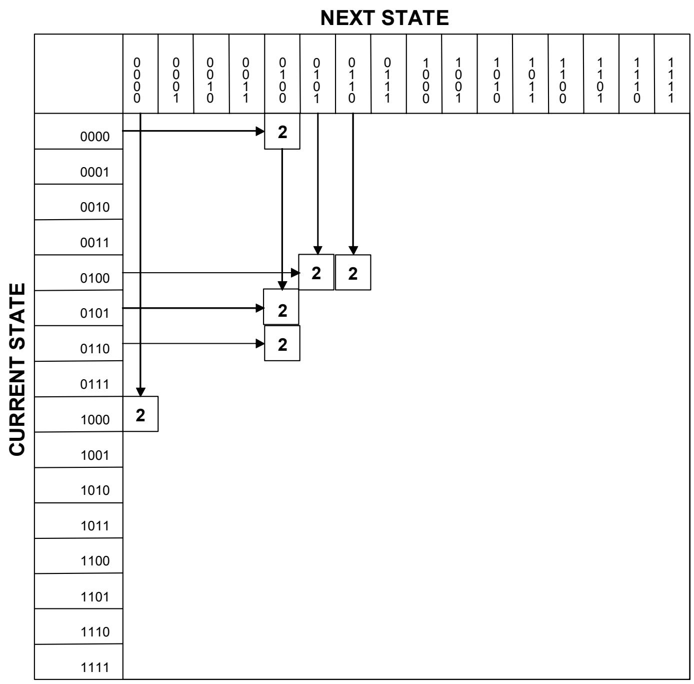


Figure 15. Sparse Matrix for Driver's 1 and 2

The resulting transitions and data entries into the sparse matrix for driver 3 are as follows:

Driver 3

<u>Transitions</u>

S. Starting state

	SWITCHES			
	Dome Light	Master Power	Panel Test	Reset
State	1	0	0	0

C. Set dome light to off position.

SWITCHES

	Dome Light	Master Power	Panel Test	Reset
State	0	0	0	0

D. Pull out and set vehicle master power switch to on.

SWITCHES

	Dome Light	Master Power	Panel Test	Reset
State	0	1	0	0

I. Push and hold both the panel light test push-button.

SWITCHES

	Dome Light	Master Power	Panel Test	Reset
State	0	1	1	0

J. Depress reset push-button on driver's alert panel.

SWITCHES

	Dome Light	Master Power	Panel Test	Reset
State	0	1	1	1

I1. Releases panel light test push-button after checks are complete.

SWITCHES

	Dome Light	Master Power	Panel Test	Reset
State	0	1	0	1

J1. Releases reset push-button.

SWITCHES

	Dome Light	Master Power	Panel Test	Reset
State	0	1	0	0

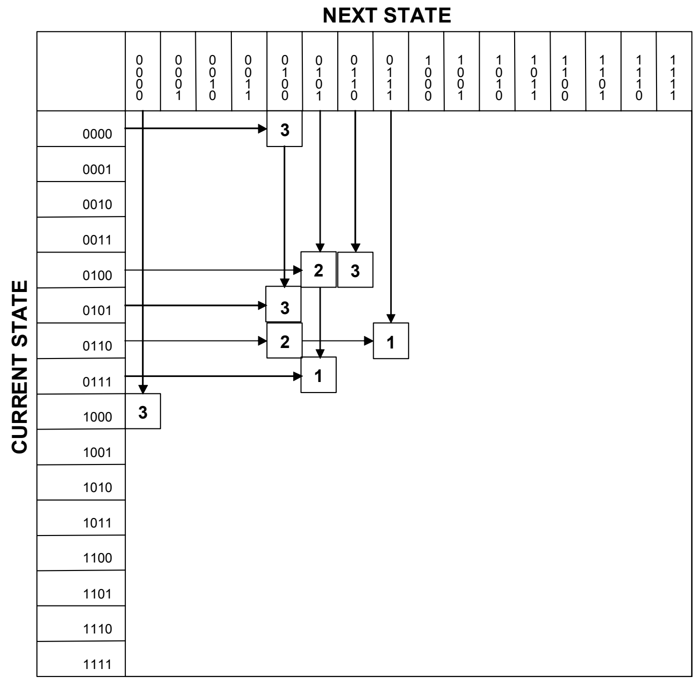


Figure 16. Sparse Matrix for Driver 3

With only 3 drivers populating our sparse matrix, as shown in Figure 16, we can provide analysis for current state; anticipated next state transitions; and task profiling. Current state evaluation can be formed by a comparison of transitional weights of a given current state. For instance, when driver 3 transitioned from 0110 to 0111 it was more probable then not that driver 3 was deviating from the transitional sequence taken by drivers 1 and 2 who both transitioned to state 0100. Although this may not be an incorrect transition, it may highlight a point of departure from an established norm that may later be used for analysis. Without knowing anything other than a current state, it is also possible to predict the most likely next state. For example, if the current state were 0100 we can conclude that there are 2 states that have weighted transitional values with state 0101 having a weight of 2 and 0110 having a weight of 3. Therefore, with the current data available, it is more likely that the next state for this task will be 0110. It is our opinion that each individual task will consist of distinguishable sets of transitional weights therefore giving the ability to probabilistically determine which task is being executed.

In the same way weighted transitions of stimuli identify an individual task, we believe that weighted transitions of individual tasks can be used to identify Battle Drills and Crew Drills facilitating the nesting nature of Army Doctrine.

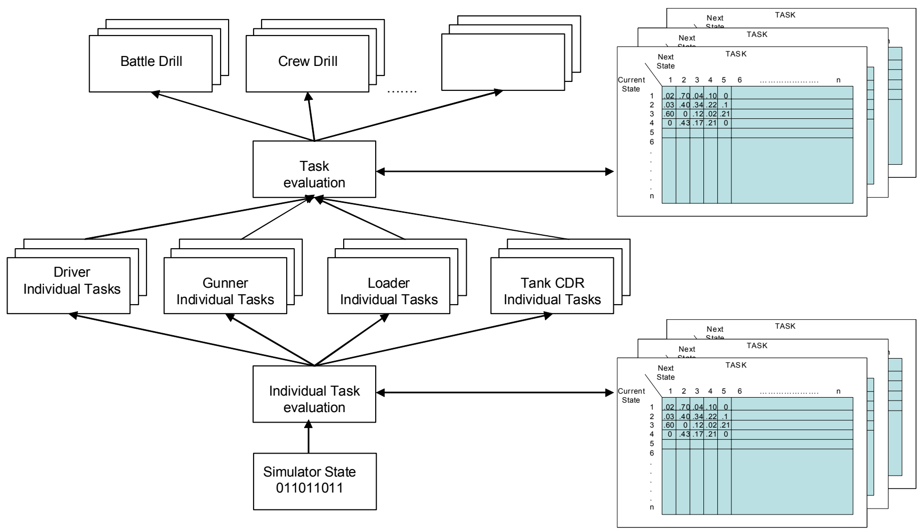


Figure 17. Weighted Transitions of Individual Tasks

IV. FOLLOW ON WORK

Recommended areas for follow on work are focused on the refinement of our proposed methodology. Areas that we recommend are consistent with the steps of our proposed methodology, these include:

- The complete definition and decomposition of the M1A2 simulator stimuli is eventually required to implement this methodology. This includes the driver, loader, gunner and tank commander stimuli.
- Continued state explosion research to further reduce state populations is necessary to insure feasibility and efficiency of possible implementations of this methodology. Testing and data collection may provide insight into additional rules for state reduction.
- Research to determine the most suitable data structures and maintenance algorithms for maintaining and evaluating doctrinally specific data structures.
- Research to determine most suitable interface to meet the needs of instructors and evaluators.
- Field testing, data gathering, and analysis.

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V. CONCLUSIONS

Our conclusion is that given the flexible and dynamic nature of Army Doctrine governing the employment of the M1A2 Tank, it is not feasible to derive a one-to-one to task mapping. However, we recommend consideration and further research of a concept that maps states to tasks through probabilities. The evaluative benefits are many. Exportability, standardization, doctrinal research and precise evaluative feedback are only a few tangible benefits that might be realized. The 'long pole in the tent' as we see it, is the state explosion problem associated with the decomposition of complex physical and functional stimuli. However, we have proposed a possible solution to mitigate this problem and suspect that current and future research may even further mitigate this problem.

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