Future Combat Vehicle (FCV): Human Factors Issues

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ABSTRACT

Background. In recent years, major changes occurred in the nature of military conflicts. Those changes defined a need for the development of new combat vehicles that are smaller, faster, more lethal and more survivable. Such vehicles should be able to achieve the same operational goals with lower costs in equipment and personnel. Goal. The Future Combat Vehicle (FCV) program contains the development of a lighter armored vehicle that will be operated by two operators, a commander and a warrior. Operators will be seated side-by-side in the hull with closed hatches. They will perceive the Surrounding environment through various electronic devices, and control the vehicle with integrated, hands-on controls. This new concept raises challenges for designers, especially in two domains: (1) maintaining the required level of combat task performance despite reducing team size from four to two warriors, and (2) maintaining situation awareness while operating from a closed vehicle without any direct view of the outside world. Method. The vehicle design process included various technical, operational and human factors aspects, including (a) operational concept, (b) technical design, (c) maintenance approach, (d) specifying Tactics, Techniques, and Procedures (TTPs), and (e) task analysis and user interface design for the experimental phases. The IDF ARMY BattleLab conceptualized the operating concept, proposed TTPs and various technologies that should support the two operators of the vehicle. Two experiments were performed. In the first experiment each vehicle operated independently, whereas, in the second they operated as a two-vehicle platoon. Results. Initial results show that the new operating concept enabled the reduction of team size without negatively impacting overall performance in a single vehicle; however, some decrease was found in operators' situation awareness and performance when the tank commander had to command a platoon from FCV as compared to a traditional tank.

ABOUT THE AUTHORS

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INTRODUCTION

Background

Many of today's military conflicts are asymmetrical, confronting on one side regular army forces and on the other guerrilla forces. This situation affects, among others, the missions of armored forces. Instead of conducting large scale tank battles, tanks are required to operate in varied environments, including complex rural areas or urban areas.

Present-generation operational tanks, which were designed for the classic armored corps, are typically operated by a three or four-person crew. The commander, the gunner and the loader-signal-operator (in some tanks this task is automated) function from the turret, while the driver sits in the hull. Much of the time, the tank commander operates with open hatches (i.e., viewing the world directly). This setup has some clear advantages but also some serious disadvantages.

Advantages:

While operating with open hatches the commander can view the world directly or with the aid of binoculars. In terms of both visual acuity and field-of-view (FOV) this is still the best solution. When operating from the turret the commander's line-of-sight is aligned with the gun and with the main sighting systems, resulting in relatively easy spatial orientation.

Disadvantages:

Tanks were designed to protect their crews; when operating with open hatches the commander is exposed to a whole array of threats. However, when the commander is forced to operate with closed hatches, his spatial orientation is severely compromised. The hull and manned-turret design force a huge and extremely heavy structure, which is cumbersome and vulnerable. In addition, if the tank commander operates from an open turret, at least two (and usually three) more crew members are required (leading to bigger vehicle and more people in danger). Furthermore, the commander has no eye contact with the crew members and has to communicate with them indirectly.

Table 1. Cons and Pros of operating from open hatches

Advantages	Disadvantages
• Better visual acuity • Wider FOV • Commander's line of sight is aligned with the gun and with the main sighting systems	• Exposure to a whole array of threats. Need for huge and extremely heavy structure. • Requirement for a bigger crew. • Indirect communication between commander and crew

Suggested solutions

Modern battlefield constraints, together with new concepts and technologies, lead to various proposed solutions for enhancing operational effectiveness and personnel safety. One idea that has been tested by various military forces (Nathan, 2010; Bradford, 2013) is to build a tank with only two crew members (a "commander" and a "warrior"), both seated side-by-side in front of the vehicle hull, with closed hatches. Therefore, the turret is unmanned and only equipped with data collecting (sensors) and firing systems. An unmanned turret can be much smaller than a manned one, thereby significantly reducing the need for crew protection and thus reducing the overall size and weight of the vehicle.

This dual operator design has clear advantages; however, it poses several major human factors-engineering problems, which will be discussed below.

FUTURE COMBAT VEHICLE (FCV) CONCEPT

The human factors design of a two-person tank with a closed turret was based on previous prototypes, professional literature and a cognitive task analysis, which led to the formulation of basic human-factors design requirements for the Future Combat Vehicle (FCV).

Within this vehicle design, cognitive and psychomotor tasks have to be redesigned in order to (1) waive the need for four crew members and (2) to enhance the abilities of the two- remaining personnel. Overall workload must be maintained within acceptable limits by using various tools and methods of support and automation. Situational awareness and spatial orientation should be supported by appropriate displays and controls. Tasks that require high physical forces (e.g., gun loading) should be automated to offload the warriors.

The representation of the outside-world must follow a number of rules: (1) The warrior must have a view that is properly aligned with the real world, i.e., real size and accurate direction and location of objects in the world; (2) Both crew members must have a sufficiently large, immediate FOV and a 360 degree total FOV with a sufficient elevation and depression. Because FOV and visual acuity are limited, threat detection should be supported by technological means. Various displayed symbols and Head-Up-Displays (HUDs) are required for supporting situation awareness and spatial orientation, preferably similar to those existing in current C4I systems.

Development process

A two-person prototype of the FCV was designed, built and tested in the battle laboratory of the Israel Ground Forces Command. The prototype was based on requirements and the design assumptions outlined below. The design was based on combining operational demand with budget limitations and battlefield constrains. The design period, which is still in progress, is based on analytic analysis and design, BattleLab experimentations and physical mockup tests.

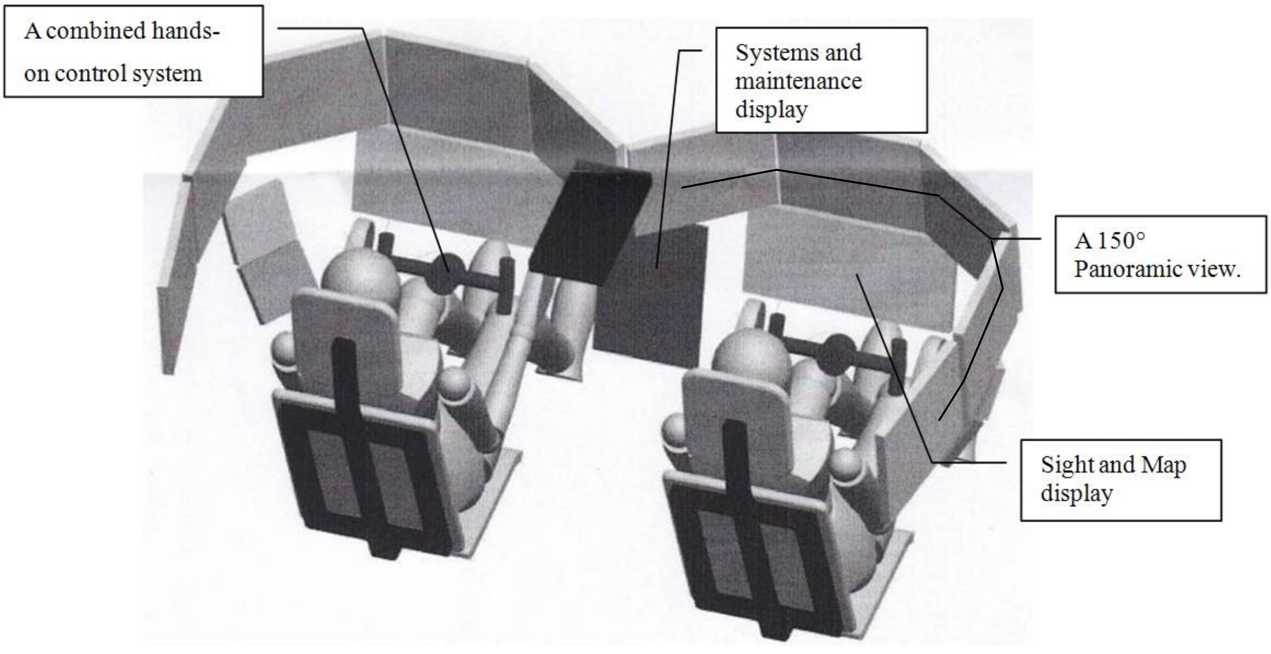

Figure 1. Crew station design

Workstation configuration

The two FCV crewmembers were seated side-by-side, in the front of the vehicle with closed hatches. The workstations for crew members are identical and both of them had access to all displays and control devices (yet one crewmember is assigned as tank commander). The outside-world view presented to operators was derived from a simulated 360° array of high resolution cameras installed outside the vehicle. A partial view of the cameras was seamlessly merged and presented to each crew member on five large displays that provided each operator with a horizontal 150° (5x30°) panoramic view of the outside-world. The front three 90° displays of the two crew members were overlapping; whereas, each crew member had an additional 60° view to his side.

The default position of the central display was forward looking, but it could be shifted to a 90°, 180°, or 270° view. An upward 70° and downwards 45° view was enabled in steps of 15° allowing a half spherical view of ground and air battle field.

In addition to the outside-world display, each crew member had a sight display, a tactical map display and a systems and maintenance display. The display monitors were touch-screens. In addition, each FCV crew member was provided with a combined hands-on control system for driving, weapon system and other systems operation.

Team work and TTPs

A default set of work allocation among the crew was defined; however, the commander was free to alter the assignment of subtasks.

The detection of Targets and threats was supported by object detection systems that displayed the detected objects in their correct world position on the panoramic view. The identification of detected objects still had to be performed manually by the crew. The touch-screen design of the panoramic displays supported the identification phase by allowing automatic alignment of the sight with the selected point of interest.

SIMULATION EXPERIMENTS

Objectives

Two experiments were performed in order to test the viability of the proposed FCV design, and compare FCV's crew performance of simulated missions to performance of the same missions in an existing four-man-crew tank. The major human factors hypotheses were:

(1) The two operators crew will perform equally well on defined missions when compared to the existing four crew tank,
(2) The commander and the warrior will operate effectively from the vehicle's hull, perceiving the world through artificial sensors, and the various display devices will provide sufficient situation awareness and spatial orientation.

Work allocation modes among the crew were not manipulated; rather, they were left open for operators to select their preferences.

Method

The experiment was performed at the Battle Laboratory of the Israel Defense Forces (IDF) Army.

Simulator: An accurate ~1m x 4m physical setup of the FCV crew station was built (Figure 1) and integrated into a logical vehicle simulator simulating motion, visualization, combat abilities and sensitivity to damage of the vehicle. An existing simulator of a current four-person tank (CT) was used as for the control tasks; thus, two vehicle simulators - FCV and CT were evaluated during each scenario.

The outside-world view was simulated using the Tiltan© visualization engine. Operational scenarios were designed by subject matter experts (SMEs) and were simulated using MAK VRForces© computer generated forces (CGF). Simulated scenarios included realistic representations of various geographical areas, in which a variety of friendly and enemy forces were positioned. Those included tanks, armored vehicles and a variety of anti-tank weapons.

A total of 16 experimental scenarios were used in the experiment, in addition to 4 training scenarios. During each scenario, vehicle teams had to perform a specified mission including navigating, selecting a safe route, detecting and striking targets, avoiding or striking threats and avoiding obstacles.

Participants: Four crews (eight participants) of experienced tank operators participated in the two experiments (two crews in each experiment).

Experimental Design: A within participant design was used. Each experiment lasted five full working days, consisting of two learning and training days, two and a half days of experimental runs, and half a day of debriefing and completing questionnaires. Each team performed all operational scenarios on the FCV and on the CT. Order of performance on the two systems was balanced between crews. While one crew was performing on the FCV, the other performed on the CT and vise versa. Slight modifications in the operational scenarios were made during the shift from FCV to CT or *vise versa*, in order to prevent order effects, but scenarios were equivalent in terms of difficulty.

Figure 2. Crew station design

Independent variables included Vehicle type (four-person CT or two-person FCV), combat area (urban, rural, and open) and task allocation (for example - who drives the vehicle and who Acquires targets).
Dependent variables included:

- Number of targets detected and destroyed and response times
- Number of hits by enemy threats
- Collisions and hits of obstacles
- Rollovers due to misunderstanding of slopes

Operational debriefings of the main scenarios were executed; participants were debriefed after each scenario, at the end of each day and at the end of the experiment. Debriefing included a discussion addressing the four main research questions, and filling out detailed questionnaires.

Each team was continuously monitored by a senior (SME) who evaluated their performance. In addition, the experiment was monitored by a human factors expert.

Workload and situation awareness (SA) evaluations were based on performance of the operational tasks and on the evaluation of the SME. In addition, the subjects were asked to evaluate workload in the summarizing questionnaires.

Experiment I

The goal of the first experiment was to test the feasibility of the basic operation of FCV. Hence, each vehicle (FCV or CT) operated alone, not as a part of a fighting unit, even though this is not the normal mode of operation of tanks. The following issues were examined: (1) the teams' ability to successfully perform their operational missions, (2) the ability to maintain situational awareness and spatial orientation, (3) examination of working methods and work allocation within the team, and (4) examination of the designed displays and controls and the resulting workload.

Results

<u>Performance</u>

The quantitative comparison between mission performance with FCV and with CT did not yield significant results[1]. Overall success in mission performance was similar in the two types of tanks. In both systems, the teams depended on supporting systems for the detection of targets and threats. Some difficulties in maintaining SA were observed across both groups, especially when more than two concurrent operational events had to be handled. The SME monitor noticed that during such situations, communication messages had to be repeated several times. Occasional difficulties in integrating the direct view of the world with the bird's-eye's view of the tactical display were observed, resulting in impaired spatial orientation; This difficulty was identified by the SME monitor who recorded cases of difficulty in detecting in the outside-world-objects that were represented on the tactical display. Occasional misevaluation of slopes resulted in rollover incidents of FCV. Questionnaire results supported these observations, and showed that the operators were aware of the difficulties and resultant performance decrements.

[1] Due to information security limitations quantitative details were wiped out of the paper

Discussion

Design issues related to FCV

The structure of the vehicle concealed the close vicinity around FCV, resulting in difficulties in distance estimation of threats and some hits of obstacles, especially in urban scenarios. The outside-world view of the FCV was evaluated as excellent. The decision to enable only 90 degrees horizontal shifts (as opposed to continuous shifts) was well accepted and justified. (Vertical shifts were not applied in Experiment I).

The use of touch screens for handling objects was very well accepted and resulted in very effective communication amongst the team. These findings should be taken cautiously, however, and be tested in a real, vibrating environment.

Operating methods related to FCV

Work allocation between crew members depended on the situation as well as on personal preferences of FCV commanders. In the default state, the commander was responsible for outside communication and for handling target and threats. In parallel, the warrior drove and navigated the vehicle and, whenever possible, supported the screening process (examining and identifying detected objects). On several occasions, commanders decided to make changes, for example, assigning the responsibility for near targets to the warrior, while the commander was taking care of the far areas of interest (AOIs). An additional performance strategy that evolved during the experiment was to let the one who detected a target/threat to deal with it directly. That strategy affected responsibly bounds and brought about a more cooperative, rather than an authoritative working style. That kind of commander-subordinate relationship is similar to the one practiced among UAV and helicopter crews and demands appropriate training and maturity.

In FCV, the role of the warrior is much more diverse than in existing tanks. It will, therefore, be required to broaden and intensify the training of future personnel. Specifically, it seemed that the FCV warrior should have professional skills (e.g. navigation and situation analysis skills) that are very similar to the commander's skills, excluding command skills.

Note: the design of the new vehicle poses additional human factors challenges that can be investigated only in a vehicle moving in a real environment. Most notably, illusory motion effects of the world-view may occur when the cameras are fixed to the vehicle, thereby moving in the same frequency as the operators' bodies. This effect has also been reported to cause motion sickness (Coyne et al, 2008). Regarding the observed difficulties in understanding the outside-world-view from the tactical display, it was hypothesized that a three dimensional (3D) mode of representation on the tactical display might alleviate the problem.

Conclusions

The overall conclusion of both the participants and experimenters was that the design of FCV was feasible, and could serve as a good starting point for further development. Based on these results, various modifications and improvements to the display system were specified (as described below).

FCV Design Enhancements

The principal change was made in the role of the tank commander. Whereas in the first experiment, the commander controlled only his own vehicle, in the second experiment the tank commander played the role of a platoon commander and had to command an additional tank. Due to laboratory limitations, the platoon consisted of one FCV and one CT tank. Thus, the platoon commander could function from either of them.

In addition, various display and control improvements and modifications were made in the FCV simulator:

- A realistic top-down visualization of the close vehicle vicinity, including self position, was displayed. This enabled the warrior to see the exact position of the vehicle in the world and therefore avoiding object hits. It is assumed that such representation may be technically possible in the foreseeable future.
- An integrated control device was introduced, enabling rapid shifting between the control of the vehicle (driving) and the control of weapon systems.
- Vertical control of the outside-world display was configured, enabling 75 degrees of elevation and 45 degrees of depression, in steps of 15 degrees.
- A new horizontal indicator presented the angular position of the vehicle on the ground; warnings were displayed when the vehicle approached a rollover danger zone.

Experiment II

The goals of the second experiment were similar to those of the first experiment, and examined crew performance across both CT and FCV simulators. However, now the commander acted as a platoon commander, commanding both vehicles either from the FCV or from CT.

Results

In general, the findings of experiment II confirmed those of experiment I. The concept and the design of the crew-station were very well accepted, emphasizing the integrated controls which were highly rated.

The additions and modifications described above solved some of the difficulties encountered during experiment I. The top down view prevented collisions with outside-world objects; rollovers no longer occurred due to the new indicator.

The major finding of experiment II, however, was that when the tank commander acted also as a platoon commander, his ability to perform both the vehicle operating and the commanding tasks was seriously compromised. The SME monitor noticed that when the commander was busy performing tasks in his own vehicle, the command of the platoon was reduced and vice versa; i.e., the vehicle and the platoon command tasks could not be performed concurrently and the demand for either of them tended to disrupt the performance of the other one. In this respect, the CT with its larger crew had a significant advantage. An average of 43 percent of targets was destroyed when the commander operated from the CT, as compared to an average of only 27 percent from FCV.

CONCLUSIONS

The present design of FCV was very well accepted as a starting point for further development of future vehicle within the platoon. The ability to perform the operational tasks and maintain good SA and spatial orientation were positively impacted by the availability of some of technologies that were used in the simulation, including reliable automatic target detection, accurate calculation of the objects' location in the world and their display on the outside-world display, and an accurate top down display of the near vehicle vicinity (including one's own position, or an alternative solution that compensates for camera FOV limitations). Some of these technologies are not well matured yet and need to be developed and examined in combat environments. Those developments should include software and algorithm advancements as well as better fitting to a military moving environment.

Platoon commanders' performance on FCV was not satisfactory, as indicated by the relatively low rate of target hits. Clearly, commanders (platoon commanders and higher), require additional support to successfully complete missions similar to those examined in this study. Such support could be either technical (more automation, e.g., automated target recognition and acquisition systems, autonomous driving, decision support systems) or human (adding a third crew member – which would require new processes of task analysis and of system redesign). The choice between these two approaches should be relayed not only on technological or human factors considerations but also by the perspective of minimal team and unit size, meaning that team size affects not only the FCV task performance but also the logistics and redundancy issues that may be crucial during combat.

FURTHER RESEARCH

Further research should address some more issues that arose due to reservations of the current research, such as the expanding of sample size and examining research questions in more varied scenarios. Other issues contain changes and improvements that were discussed in the results of the current experiment, such as (a) designing and testing a three-person crew station for command vehicles (b) performing field tests, particularly in regard with driving, with the indirect representation of the world view; testing the stability of the picture, possible effects of virtual motion and motion sickness problems and (c) adding and testing a 3D mode of the tactical display.

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