한국기계가공학회지, 제20권, 제2호, pp. 14∼22(2021.02) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 20, No. 2, pp. 14~22(2021.02) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2021.20.02.014

Development Direction of Reliability-based ROK Amphibious Assault Vehicles

Ilho Baek* , Jusung Bong* , Jangwook Hur*,#

*Department of Mechanical Engineering, Kumoh National Institute of Technology

신뢰성 기반 한국군 차기 상륙돌격장갑차 발전방향

백일호*, 봉주성*, 허장욱*,#

*금오공과대학교 기계공학과

(Received 09 September 2020; received in revised form 06 October 2020; accepted 24 October 2020)

ABSTRACT

A plan for the development of reliability-based ROK amphibious assault vehicles is proposed. By analyzing the development case of the U.S. EFV, considerations for the successful development of the next-generation Korea Forces amphibious assault vehicle are presented. If the vehicle reliability can be improved to the level of the fourth highest priority electric unit for power units, suspensions, decelerators, and body groups, which have the highest priority among fault frequency items, a system level MTBF of 36.4%↑ can be achieved, and the operational availability can be increased by 3.5%↑. The next-generation amphibious assault vehicles must fulfill certain operating and performance requirements, the underlying systems must be built, and sequencing of the hybrid engine and the modular concept should be considered. Along with big-data- and machine-learning-based failure prediction, machine maintenance based on augmented reality/virtual reality and remote maintenance should be used to improve the ability to maintain combat readiness and reduce lifecycle costs.

Key Words : Amphibious Assault Vehicle(상륙돌격장갑차), Reliability(신뢰성), Failure Frequency Items(고장다빈도 품목), Mean Time Between Failure(고장간 평균시간)

1. Introduction

Given that the demand for wartime amphibious operation in South Korea is high owing to the geographical characteristics of the Korean Peninsula, which is surrounded by sea on three sides, it is essential to strengthen the amphibious military capability of the country to conduct deep mobile operations in response to nuclear bombs, missiles, and weapons of mass destruction from North Korea. Among the essential weapon systems for amphibious operations are assault amphibious vehicles (AAV). The AAVs operational in Korea were manufactured

Corresponding Author : hhjw88@kumoh.ac.kr
Tel: +82-54-478-7399

30 years ago when the relevant technical know-how was obtained from the US. Thus, the existing AAVs are aged and inadequate in terms of their capabilities, and the integration of new AAVs into the weapon systems is required[1].

In recent years, the development of the next-generation AAVs in the US with a budget of $1.5 billion was canceled owing to reliability issues and a rapid rise in the development and production costs[2]. In this light, the next-generation AAVs would require not only reinforced amphibious and ground combat capabilities in accordance with the new amphibious warfare doctrine but also improved combat readiness and reduced lifecycle cost through enhanced system reliability[3-4]. Thus, in this study, the development cases of next-generation AAVs in advanced nations are analyzed, and the development of the system that satisfies the operation concept and required performance, proactive application of technologies of the Fourth Industrial Revolution, and the measure to improve the reliability of frequently failed parts through the similarity system analysis are reviewed as the considerations during the development of next AAVs for Korean troops thereby proposing a measure to develop the next-generational AAVs for Korean troops based on the reliability.

2. Analysis of development cases of AAVs in advanced nations

2.1 Current development status in major advanced nations

Because AAV development is cost intensive, very few such development programs are underway in advanced nations, namely the expeditionary fighting vehicle (EFV) program in the US and the Mitsubishi amphibious vehicle (MAV) program in Japan.

2.2 EFV program in the US

US forces have been using the AAV-7A1 since 1972. The EFV program was started in the US in 1988 to replace AAV-7A1, as shown in Figure 1 and summarized in Table 1, to accommodate the most required weapons systems acquired by the US marine corps[5].

General Dynamics Land Systems designed a mount for the aluminum hull and applied an MT 883 model with two operation modes: a high-power mode for planing over the sea and a low power mode for land travel. Shrouded Honeywell waterjet propulsors are integrated into each side of the hull, and they generate more than 2,800 horsepower of thrust. The new AAV can maneuver at a maximum

Table 1 Specifications of EFV

Type	Specifications
Mass	Gross vehicle weight fully loaded 79,300 pounds(35.97 metric ton)
Length	10.67 m(35 ft)
Width	3.66 m(12 ft)
Height	3.28 m(10.7 ft)(turret roof)
Crew	3 crew
Passengers	17 fully equipped Marines(EFVP), 7 command crew(EFVPC)
Operational range	Land : 523 km(325 miles), Water : 120 km(74 miles)
Maximum speed	Land : 72.41 km/h(45 mph), Water : 46 km/h(28.6 mph)

waterborne speed of 45 km/h, and. It uses an Ethernet network based on a commercial router for the vehicle’s internal and external communications.
An AAV takes off from a landing ship, which is typically 3 km away from the landing spot on the coast. Even so, amphibious operations are vulnerable to threats from enemies because of the advancement in the enemies’ radar detection range and defense capabilities in general. To overcome the threat, the US Navy developed a new concept called “ship to objective maneuver (STOM)” and formulated a new strategy called operational maneuver from the sea (OMFTS) to cope with future amphibious warfare patterns, as shown in Figure 2. To this end, the US marine corps demanded a next-generation EFV with excellent combat performance, for instance, a 30-mm gun, which was comparable to that equipped in the Bradley Fighting Vehicle, and three times the water speed and twice the armor protection capability compared to those of existing AAVs.

The most significant problem with the EFV was lack of reliability. For example, two out of 11 tests on sea driving and landing did not achieve the required performance goals. The US marine corps had to input $ 1.5 billion, which was five times the original development cost of $ 300 million, as well as spend eight years more than the planned schedule, to resolve the series of the problems that were encountered during the development phase.

Fig. 1 EFV under sea test

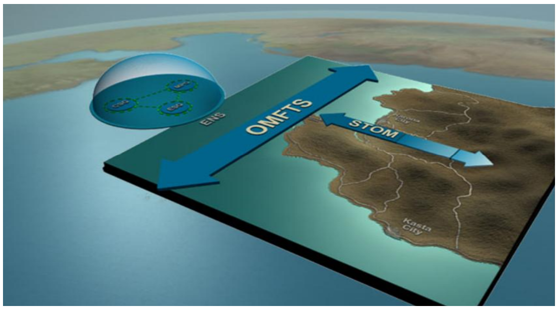

Fig. 2 OMFTS concept

Fig. 3 MAV drive system test

Table 2 Specifications of MAV

Type	Specifications
Mass	30~35 ton(estimated)
Crew	3 crew
Passengers	15 fully equipped Marines
Water speed	46.3 km/h(Maximum)
Horsepower	3,000 HP(Maximum)
Engine	8VA34WTK Series

As a result, the EFV turned out to be the most expensive armored vehicle, and the estimated unit price exceeded $ 2,200. Thus, the US Department of Defense canceled the EFV project in 2011 because it could not endure the large increase in cost[1].

2.3 MAV program in Japan

The MAV program in Japan was led by

Mitsubishi Heavy Industries as a form of advanced development. The next-generation amphibious vehicle model was revealed at MAST Asia 2017 in June 2017, as shown in Figure 3 and summarized in Table 2. The MAV is a kind of Japanese EFV that is very similar to the US' EFV, which failed in the past. Instead of using the Type 10 main battle tank (MBT) V10 engine, it used an improved V12 engine to enhance the output from 1,200 horsepower to 1,800 horsepower, and existing parts were to the extent possible to promote economic feasibility by maintaining commonality and compatibility.

Its propulsion method was the same as that of EFV, in which the output was raised to 3,000 horsepower through seawater cooling, to achieve a maximum waterborne maneuvering speed of 46.3 km/h. However, in the MAV project, the same waterborne speed as that of the EFV was demanded with a smaller and narrower vehicle body than that of the EFV. As a result, the internal structure of the MAV was very complex, resulting in difficulties in maintaining its operation.

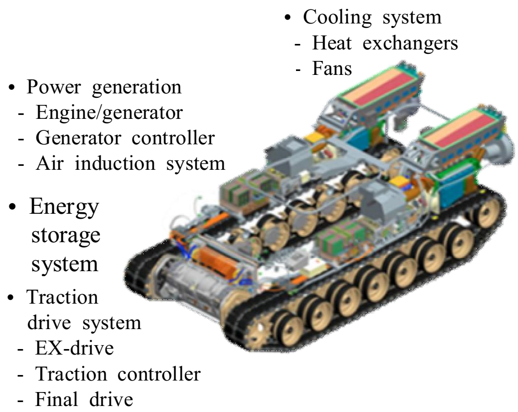

Fig. 4 AAV with hybrid engine

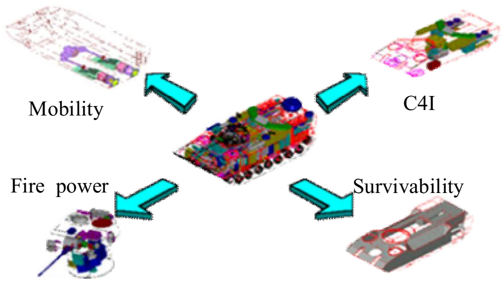

Fig. 5 Modular AAV

Table 3 System construction considerations

Division	Requirements	Related apparatus
Structure design	• It is convertible to the hull structure like the high speed well so that the stable driving possible in the sea mode • Combined power transfer and car body transformation in transient mode • Ensures mobility and viability equivalent to other maneuvering systems in land mode	Body, high power engine, power switch, transmission etc.
Power unit	• Control and operation of devices related to each mode(resolution, land, conversion) efficiently • Optimization design of limited space	High power engine, transmission, power switch, water jet etc.
Suspension device	• Ensures performance of high-speed water-surface operation through reduced drag • High mobility to ensure joint fighting performance with other maneuvering weapons systems	Variable form / active type suspension system
Armed fire control device	• Thermal projection during maneuver	Medium caliber, firepower, firing stabilization device
Communication device	• Other combat systems and joint fighting operation capability \ • Share information that is organically necessary for the electrical field elements in real time	C4I system and communication network

Thus, it will be difficult for the MAV to enter overseas markets in terms of price competitiveness.

3. Next AAV for the Korean military Considerations during development

3.1 Development in accordance with the operational concept and required performance

The structural design, power unit, suspension unit, arming device, fire control unit, and communication device should be developed in accordance with the operational concept and performance requirements. The design requirements of the main devices are presented in Table 3. The North Korean army is expected to arrange large-caliber weapons in a multilayered fashion during amphibious operations and concentrate its forces in the order of open seas, offshore water, and inland areas. Thus, the waterborne speed of AAVs is very important for ensuring its survivability, and it is necessary to build a system to implement this operation concept.

In addition, the application of a hybrid engine is a consideration, as shown in Figure 4, to improve the operational performance capability by using noiseless movement when performing some operations and to optimize the fuel consumption when the AAV is stopped or moving slowly. Furthermore, the AAV not only carries armored personnel but also requires systematization considering the operations and maintenance, as well as economic feasibility, such as AAVs for command and AAVs for securing a passage. Thus, the division of armored personnel boarding in the AAV should be modularized, as shown in Figure 5 and

Table 4 Modular AAV

Module	Components	
Mobility	- High power density propulsion & auxiliaries - High power water jets	- Hydraulic systems - High efficiency heat exchangers
C4I	- Displays - Situational awareness - Wireless communication - Position locating / navigation	- Obstacle derection & collision avoidance - Non-cooled thermal viewers - Night vision devices
Firepower	- 30mm ammunition	- Fire control systems
Survivability	- NBC systems - Smoke generators / grenades - Fire sensings & suppression	- Laser protected vision / periscope - Environmental control - Noise attenuation

Table 5 Fault diagnosis sensor type and data features

Type	The details
Parameters	- Vibration, Temperature, pressure, shock, acoustic level, strain, stress - Voltage, current, humidity level, contaminant concentration - Usage frequency, usage severity, usage time, power, heat dissipation - Corrosion, oil quality
Data feature	- Magnitude, variation, peak level, rate of change
Precision	- Initial specs, calibration, low-drift, multi-sensor data fusion

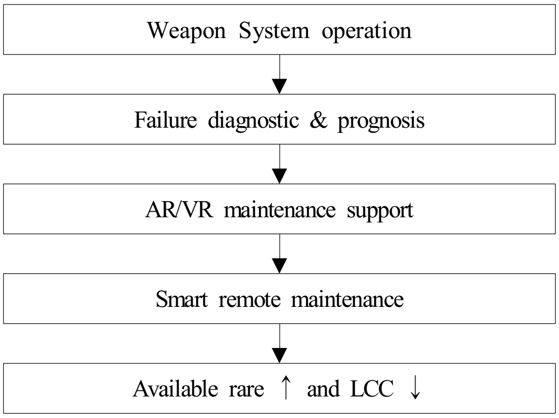

Fig. 6 Effect of the 4th industrial revolution technology

Table 4, thereby enabling fast replacement or renovation depending on the mission and circumstance.

3.2 Application of technologies from the Fourth Industrial Revolution

With rapid technical advancement, the emergence of the Fourth Industrial Revolution based on artificial intelligence has heralded changes in weapon system operations and maintenance. Figure 6 shows the emerging workflow. First, fault-diagnosis sensors for vibration, temperature, and pressure, should be attached to the main devices of the weapons systems, as presented in Table 5, and faults are diagnosed and predicted by classifying them after learning the fault status through the application of machine learning techniques to big data on measurable parameters. If these data are accumulated, they can be used to predict the remaining valid life. Second, it is necessary to drive advanced maintenance support operations, including remote maintenance through augmented reality (AR) and virtual reality (VR). When applying AR and VR, a head-mounted display (HMD) that is worn like glasses can be used in real maintenance fields, as well as during education and training.

Fig. 7 AR-based maintenance manual visualization

Currently, mechanics perform maintenance tasks by referring to technical or electronic manuals, such as two-dimensionally expressed books. Moreover, it is an essential requirement considering the characteristics of AAV maintenance hierarchy and the circumstance of the marines corps that user maintenance to direct support maintenance is directly maintained by the Korean armed forces, while general support maintenance and depot maintenance are handled by contract maintenance. That is, mechanics whose expertise in maintenance is relatively low can see a part being subjected to maintenance by using an AR device, as shown in Figure 7, where a three-dimensional (3D) modeled object is overlaid on real space automatically through object recognition technology to perform the virtual training and maintenance. This is expected to improve maintainability by overcoming the physical limitations of maintenance training.

In addition, maintenance contractors can check the device status in real time remotely through the AR device to support the mechanics at the site to take immediate action, thereby achieving a dramatic reduction in administrative and logistics support time.

Accordingly, if faults are predicted in advance, and failure exclusion activities can be performed in preparation of the faults at the optimal time before the lifetime of the part ends, the operation rate can be improved, and the lifecycle cost can be reduced.

Table 6 Failure status by configuration

Division	Device name	Failure (number of times)	Annual failure (number of times)	MTBF (H)	Failure rate (%)
Chassis	Environmental control system	306	0.23	333.3	0.30
	Controller and brake ring cage	766	0.58	130.1	0.77
	Suspension and end reducer	2,085	1.58	**47.8**	2.09
	Seawater propulsion & resolution steering system	963	0.73	103.5	0.97
	Hydraulic device	1,046	0.79	95.3	1.05
	Electric device	1,376	1.04	72.4	1.38
	Fuel system	520	0.39	191.7	0.52
	Survival device	310	0.24	322.6	0.31
	Communication navigation system	140	0.11	714.3	0.14
	Power unit	3,707	2.80	26.9	3.72
	Chassis incidental device	1,935	1.46	51.5	1.94
Turret	Turret device	441	0.33	226.1	0.44
	Turret electrical device	361	0.27	276.1	0.36
	Armament device	617	0.47	161.6	0.62
	Fire control device	44	0.03	2,265.6	0.04
	Turret incidental device	49	0.04	2,034.5	0.05

3.3 Improvement of reliability infrequently failed parts of a similar system

Currently operational AAVs have more faults in the vehicle body area than in the gun turret area because of their operation across land and water; moreover, they are used more for driving-oriented training operations than firing exercises. According to the Reliability, Availability, and Maintainability (RAM) analysis report[6] published by the Defense Agency for Technology and Quality (DTaQ), the power unit is the part that fails the most frequently, followed by the suspension unit, final reduction gear, and accessories in the vehicle’s body, as presented in Table 6. Thus, it is necessary to take pre-emptive measures to improve their reliability at the component level before the development of the next AAV.

It was considered that the failure rate would improve slightly upon the application of a robust design after analysis of the causes of failure and implementation of measures for frequently failing parts.

The analysis report published by DTaQ calculated the mean time between failure (MTBF) at the system level and it was 8.8 h, while the operationally available rate was 86.1%[6]. Here, if the reliabilities of the power unit, suspension unit, final reduction gear, and accessories of the vehicle's body among the other frequently failing parts can be improved to the level of the electric devices, which had the fourth highest priority, the results are presented in Table 7. The quantitative effects of the improvements summarized in Table 7 on the MTBF and operational availability at the system level were analyzed using the Markov process simulator (MPS)

Table 7 Existence and change conditions

Device name	Existence conditions		Improved conditions	
	MTBF(H)	Failure rate(1/MTBF)	MTBF(H)	Failure rate(1/MTBF)
Power unit	26.9	3.72%	72.4	1.38%
Suspension & reducer	47.8	2.09%	72.4	1.38%
Electric device	72.4	1.38%	72.4	1.38%
Chassis incidental device	51.5	1.94%	72.4	1.38%

Table 8 Analysis results using MPS software

Type	Existence conditions	Improved conditions	Remark
System MTBF	8.8H	12.0H	36.4% ↑
Operation Availability	86.1%	89.1	3.0% ↑

software[7-10]. The MPS software was used to implement an analysis model that satisfied a specific reliability level by converting a transition matrix into a probabilistic matrix through the Chapman–Kolmogorov differential equation with RAM parameters, such as MTBF, mean time to repair (MTTR), and administrative or logistic downtime (ALDT), as well as the input conditions of unit price, quantity, and maintenance labor cost, as the cost parameters and performing this conversion repeatedly over time; the C, C++, and C# programming languages were used for this purpose. The analysis results are presented in Table 8. The system MTBF was improved from 8.8 h to 12.0 h (an increase of 3.2 h or 36.4%), and the operation availability was improved by 3% from 86.1% to 89.1%.

Thus, it is necessary to conduct thorough analysis and pre-preparation of frequently failing parts, such as the power unit, suspension unit, final reduction gear, and accessories of the vehicle's body, of currently operational vehicles for the successful development of the next-generation AAV for Korean armed forces.

4. Conclusions

In this study, considerations to develop the next-generation AAV for the Korean military were proposed by analyzing the development cases of AAVs in advanced nations. The conclusions of this study are summarized as follows:

1) It is necessary to build a system that satisfies the operational concept and performance requirements of the next-generation AAV, and systematization of the modular concept and use of a hybrid engine should be considered.

2) Along with the failure prediction by applying Fourth Industrial Revolution technologies, such as big data and machine learning, the next development should contribute toward maintaining combat readiness and reducing the lifecycle cost through the application of maintenance concepts and remote maintenance based on AR and VR.

3) It is necessary to thoroughly analyze frequently failing parts, such as the power unit, suspension unit, final reduction gear, and vehicle body accessories of currently operational AAVs and to engage in pre-technical development.

4) If the reliabilities of the frequently failing parts can be improved to the level of the electric devices, the system MTBF and operational availability will increase by 36.4% and 3.0%, respectively.

Acknowledgments

This research was supported by the MSIT(Ministry of Science and ICT), Korea, under the Grand Information Technology Research Center support program (IITP-2021-2020-0-01612) and supervised by the IITP(Institute for Information & communications Technology Planning & Evaluation

REFERENCES

1. "Korea Marine Corps' Core Power, Amphibious Assault Vehicle(KAAV)", DAPA, 2014.(https://m.blog.naver.com/dapapr/220089713654)
2. “EFV, The Next Amphibious Assault Vehicle”, The Defense Industry in the Story, DAPA, 2010. (http://blog.naver.com/dapapr/110092407292)
3. Hur, J. W., “Operation Requirement Document of Amphibious Assault Vehicle for Pathway”, DTaQ, pp. 17-52, 2019.
4. Park, S. and Lim, H. J., “Trends of Development for Advanced Amphibious Assault Vehicle", DTaQ, pp. 13-15, 2009.
5. Hwang, J. Y., “Development Trend of World Next Generation Amphibious Assault Vehicle for KAAV-II", Defense and Technology, Vol. 479, pp. 110-129, 2019.
6. DTaQ, “RAM Analysis Report Using Ground System Field Data(Korea Amphibious Assault Vehicle)", 2019.
7. Shin, S. H. and Lee, H. J., "A Practical Method for Predicting Initial Maintenance Time to Repair(MTTR) Using Maintenance Complexity in Equipment Design", SASE 2019 Spring Conference. P12-5, 2019.
8. Kim, B. H., Kim, S. K., Pagulayanand, D. and Hur, J. W., "A Study on System Availability Analysis Utilizing Markov Process", Journal of Applied Reliability, Vol. 16, No. 4, pp. 295-304, 2016.
9. Kim, H. S., Kim B. H. and Hur, J. W., "System Availability Analysis Using Markov Process", Journal of KOSSE, Vol. 14, No. 1, pp. 36-43, 2018.
10. Kim, H. S., Choi, S. D. and Hur, J. W., "Development of Design Alternative Analysis Program Considering RAM Parameter and Cost", Journal of the Korean Society of Manufacturing Process Engineers, Vol. 18, No. 6, pp. 1-8, 2019.