Evaluation of Automatic Transmissions For Use In Military Wheeled Vehicles

(Decision Risk Analysis)

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The use of automatic transmissions has penetrated deeper into the commercial environment in the last few years and applications now include not only passenger vehicles, but heavy trucks and off-road type vehicles as well. Military experience with automatic transmissions has been concentrated on tracked vehicles with only limited use in wheeled vehicles (such as the 44-passenger bus, the 2-1/2-ton truck and, more recently, the GOER vehicle, the M656 truck and the Heavy Equipment Transporter). Military experience with automatic transmissions in wheeled vehicles is much less than the 30-plus years of commercial experience. Recognizing the potential of automatic transmissions from the widening field of commercial applications, the US Army Tank-Automotive Command initiated a study in December 1971 to explore the use of automatic transmissions in the tactical wheeled vehicles procured and used by the United States Army. The purpose of the study was to facilitate policy decisions and materiel selection concerning the use of automatic transmissions in these vehicles. It was designed to consider Army wheeled vehicles in the 1/4, 1-1/4, 2-1/2, 5 and 10 ton weight classes (all body types within these weight classes were regarded collectively) for the 1972-1980 time-frame. New vehicle procurements and approved product improvement programs for that period were included. While it was felt that the military environment more closely resembled the commercial off-road application, the adoption of automatic transmissions to all categories of military wheeled vehicles was examined.

Criteria were established for selection of automatic transmissions for the study. They had to (1) meet military requirements (ratio, torque input, speed, etc.) and (2) be commercially available by January 1973. Several types of automatic transmissions were considered; the torque converter fully automatic, the torque converter power shift, and the hydromechanical. Another type, the positive synchronizing automatic transmission, was not considered because it was still in the developmental stages at the time the study was performed and no firm production dates had been established. Such factors as total cost of ownership, physical fit, operation, effects on vehicle performance, durability, reliability, maintainability and human engineering were also considered, as well as existing and proposed regulations of the Environmental Protection Agency and the Department of Transportation. These will be discussed later.

Study Methodology

The study was accomplished by a study team chaired by a member of the Systems Analysis Division, Plans and Analysis Directorate, US Army Tank-Automotive Command. Members from engineering, quality assurance, procurement and supply activities were included in the study team. The study data

base consisted of, on the commercial side, field reports, market studies, and sales literature. On the military side, 25-years experience with automatic transmissions in tracked vehicles, experience gained with the 2-1/2 ton truck in the Korean War, limited data from the aforementioned recent application in the M656 (5-ton), the GOER family and the Heavy Equipment Transporter, and limited data from test rigs using automatics in 1/2, 2-1/2, 5 and 10 ton vehicles were considered.

A number of factors which could enter into a decision regarding the type of transmission best suited to the job were developed. These factors were broken down into five major groups and were individually assigned a value of relative importance to the decision maker (based on a value of 100). The weights were assigned after careful consideration of all factors in each of the groups.

Factor Groups	Weight
1. Cost of Ownership	30
2. Engineering/Product Assurance	20
3. Suitability for Military Application	20
4. Maintenance and Logistics Support	25
5. State-of-the-Art	5
TOTAL	100

A complete list of factors and their weights are presented in Figure 1.

Because cost is a prime decision in any decision concerning military hardware and because there is intense competition from other government agencies for tax dollars this item was assigned the highest value of the five groups. The sub-factors in this group were assigned weights according to their relative importance in the life cycle cost for wheeled vehicles.

The second factor group, Engineering/Product Assurance, is concerned with the engineering problems which may arise during conversion from manual automatic transmissions and the impact on product assurance. Warranty provisions were also considered.

The third factor group, Suitability for Military Application, reflects the fact that unless a vehicle is able to perform its assigned mission when required, it is of questionable value to the user, regardless of the cost.

The fourth group, Maintenance and Logistics Support, can have a great impact in making any decision on selection between alternatives. Equipment which is difficult to maintain and support will result in many problems in the field.

The fifth group, State-of-the-Art, is of lesser importance because all of the items considered in the study are basically commercial items and no development program is anticipated.

After all of the factor weights were assigned, a narrative was developed for each of the individual factors to explore the relative "pro's" and "con's" of automatic transmission applications. To develop this comparative narrative, the current manual transmission equipped vehicles in each weight class were used as a basis for comparison.

When the narrative analysis for each of the factors was complete, a rating system was used to summarize all of the information contained in the narratives in terms of an overall "pro" or "con" position. The rating scale ranged from -5 to +5; where -5 represents "con" automatic, +5 represents "pro" automatic and a value of 0 indicates indifference. For each factor a rating value was determined on the basis of the narrative. To associate a risk with the rating system a pessimistic and optimistic value were also determined for each factor. An example of the rating procedure is shown in Figure 2. By making use of the pessimistic, most likely, and optimistic rating values for each factor, and the usual assumptions of the normal BETA distribution of the PERT process, an average rating value and standard deviations were obtained for each factor. From this information a statement for each vehicle weight class could be made regarding the "pro" or "con" value for automatic transmissions and the probability of the decision maker erroring if he chose to use automatic instead of manual transmissions.

Study Conclusions

In summary, automatic transmissions represent a higher initial acquisition cost, but these costs are expected to be offset by lower operational cost and the overall improvement in vehicle performance and life characteristics. The results of the factor evaluation indicates that the probability of automatic transmissions having a "pro" rating range from .964 for the 2-1/2 ton truck to .995 for the 1/4 ton truck. On a "rating" scale of -5 to +5 the weighted average ratings of automatic transmissions versus manual transmissions in the 1/4 ton to 10 ton weight class ranged from +.6 to +.8. (These results are tabulated in Figure 3.) From a total system and life cycle view adoption of the automatic transmission over the manual is favored for introduction into the military tactical wheeled vehicle fleet in the 1972-1980 time period.

Specific results for each factor group are discussed below:

1. Cost of ownership.

In most cases acquisition cost for automatic transmission is greater than that of a manual transmission as reflected in the following table:

Vehicle Application	Current Manual*	Proposed Automatics**
1/4 ton trk, M151 Ser	$315	$425 to $450
1 1/4 ton trk, M151 Ser	$310	$600 to $750
2 1/2 ton trk, M44A2 Ser	$980	$850 to $2100

Vehicle Application	Current Manual*	Proposed Automatics**
5 ton trk, M809 Ser	$1,510	$1,775 to $4,025
10 ton trk, M123A1C	$2,600	$4,200 to $4,500

* Includes transmission, transfer assembly, and clutch assembly.

** Includes equivalent drive-line components at the current manual listing.

The type of transmission does not have any significant impact on operating (POL) costs. These costs are considered to be insignificant in making a selection of the type of transmission for military application.

Maintenance costs are the most important consideration in comparing manual and automatic transmissions. Maintenance cost data on commercial truck fleets indicates substantial savings with automatic transmissions. Figure 4 indicates the time to recover the automatic transmission overcost assuming a 10% savings in maintenance cost. This 10% is considered to be very conservative. An analysis of the sensitivity of the ratings to changes in assumed maintenance savings was performed with the following results

Overall Most Likely Weighted Ratings
(-5 to +5 scale)

Wt Class (Ton)	Assumed Maintenance Savings		
	10%	5%	0%
1/4	+.77	+.61	*.13
1 1/4	+.74	+.58	+.10
2 1/2	+.66	+.50	+.02
5	+.84	+.68	+.20
10	+.83	+.67	+.19

If there were no savings in maintenance costs by using automatic transmissions, naturally the overcost could not be recovered. However, due to the improved performance with automatics, numerous other favorable evaluation factors, and the weighting factors used, the total ratings for the automatic transmissions would still be on the "pro" side.

2. Engineering/Product Assurance.

Vehicle performance is a major consideration in military vehicles. The highest "pro" automatic rating values were realized in this area due to the potentials of increased performance resulting from projected "ease of use" and longer life attributes. The study group felt that the favorable experience in the commercial world would carry over in military applications and affect performance favorably.

4. Maintenance and Logistics Support

Overall ratings in this area reflected a "con" value for automatics. This was due to an increase in labor and parts support required, new manuals, initial provisioning and special tools. The study group emphasized that although the overall rating was "con" automatic, "pro" values were realized for such items as overhaul and drive-line component replacement.

5. State-of-the-Art

All of the automatic transmissions considered in this study are commercially availabe and in most cases their technical feasibility has been established.

Study Recommendations

That the top Army management regard with favor the application of automatic type transmissions to the military wheeled vehicle fleet.

Additional hardware evaluation be pursued in conjunction with approved product improvement programs to verify the correlation between the commercial off-the-road environment and the military environment.

The study shows a cost advantage for the automatic transmission on the total cost of ownership basis. This advantage principally reflects the expected increase in durability and reliability, and reduced maintenance of the total automatic drive line. Since cost is an important part in the study, it is recommended that considerable emphasis be placed on evaluating reliability and durability in pursuit of the PIP programs.

Continue surveillance of on-going investigations and developments in the commercial automatic transmission field in the interest of future military application.

Post Study Actions

The principal theme of most of the recommendations concerns whether the expected maintenance savings and other benefits are sufficient to offset the initial overcost of the automatic transmission equipped drive line. Product improvement programs (PIP's) initiated for all vehicles considered in this study, and automatic transmissions were included in these PIP's. The PIP test programs were to provide the additional data required in order to determine the future application of automatic transmissions in the Army wheeled vehicle fleet. With the advent of the WHEELS Study, however, these PIP's were cancelled. Additional PIP's have not been approved as of this writing.

FACTOR WEIGHTS

		WT
1.	Cost of Ownership	30.0
	(1) Acquisition cost	10.0
	(2) Operating cost	3.0
	(3) Maintenance cost	16.0
	(4) Salvage value	1.0
2.	Engineering/Product Assurance	20.0
	Vehicle Systems Considerations	13.0
	(1) Power take-off provisions	3.0
	(2) Seals	2.0
	(3) Transfer cases	3.0
	(4) Drive-line compatibility	3.0
	(5) Vehicle design changes	2.0
	Weight and Size Suitability	1.0
	(6) Weight	0.5
	(7) Dimensions	0.5
	Testing	6.0
	(8) Engrg tests	1.5
	(9) Quality Assurance tests	1.5
	(10) Warranty provisions	0.0
	(11) Exhaust emission control	3.0
3.	Suitability for Military Application	20.0
	Vehicle Performance	4.5
	(1) Fuel comsumption and economy	0.5
	(2) Drawbar pull	0.5
	(3) Braking ability	0.5
	(4) Acceleration	1.0
	(5) Maximum min speed	0.5
	(6) Productivity	1.0
	(7) Oil pick-up on slope	0.5

Figure 1a

FACTOR WEIGHTS (Cont'd)

	WT
Vehicle Effectiveness	3.5
(8) Reliability	
Replacement rates	1.0
Modes of failure	0.5
(9) Maintainability	1.0
(10) Availability	1.0
Vehicle Mobility	4.0
(11) Push-tow starts	0.5
(12) Initiation of vehicle movement	0.5
(13) Gear selection	0.5
(14) Power effect	0.5
(15) Weight effect	0.5
(16) Gradeability	0.5
(17) Rocking out	0.5
(18) On-road and off-road	0.5
Environmental Suitability	2.5
(19) Ease of start at low temp	0.5
(20) Cooling rqmt	0.5
(21) Submerged operation	0.5
(22) Temp range (-65 to +125° F.)	0.5
(23) Preservation and storage	0.5
Human Engineering	5.5
(24) Operator use	1.0
(25) Driver fatigue	0.5
(26) Safety	0.5
(27) User attitude (acceptance)	1.0
(28) Abuse to drive-line	1.0
(29) Driver training	1.0
(30) Noise	0.5

Figure 1b

FACTOR WEIGHTS (Cont'd)

		WT
4.	Maintenance and Logistics Support	2.5
	(1) Modular maintenance	1.0
	(2) Diagnostic testing	0.5
	(3) Maintenance allocation	1.0
	(4) Training requirements	3.0
	(5) Initial, follow-on provisioning	3.0
	(6) Publications	1.0
	(7) Mod. work orders	1.5
	(8) Scheduled maintenance	3.0
	(9) Overhaul	3.0
	(10) Unscheduled maintenance	3.0
	(11) Drive-line compl. repl.	3.0
	(12) Line item management	1.0
	(13) Special tools	0.5
5.	State-of-the-Art	5.0
	(1) Military experience	2.5
	(2) Commercial experience	1.5
	(3) State of technology	1.0

Figure 1c

Example of Rating Procedure

Factor Weights and Rating

Rating Value (-5 to +5) For Each Vehicle Type

		1/4 TON			1-1/4 TON			2-1/2 TON		
FACTOR	WT	PES	ML	OPT	PES	ML	OPT	PES	ML	OPT
COST OF OWNERSHIP	30	-2	+2	+6	-2	+2	+6	-4	+1	+6
(1) ACQUISITION COST	10.0	-3	-2	-1	-3	-2	-1	-5	-3	-1
(2) OPERATING COST	3.0	-1	0	+1	-1	0	+1	-1	0	+1
(3) MAINTENANCE COST	16.0	+3	+4	+5	+3	+4	+5	+3	+4	+5
(4) SALVAGE VALUE	1.0	-1	0	+1	-1	0	+1	-1	0	+1

Figure 2

Summary of Rating Values By Vehicle Weight Class On A -5 ("Con") to +5 ("Pro) Scale

VEHICLE WEIGHT CLASS	RATING VALUES			WEIGHTED RATING VALUES			AVERAGE RATING VALUE	"RISK"* PROBABILITY RATING
	PES	ML	OPT	PES	ML	OPT		
1/4-Ton	-.2	.3	.7	-.1	.8	1.5	.7 (.27)**	0.5%
1-1/4-Ton	-.2	.3	.7	-.2	.7	1.5	.7 (.29)	0.8%
2-1/2-Ton	-.3	.3	.7	-.4	.7	1.6	.6 (.33)	3.6%
5-Ton	-.2	.3	.8	-.2	.8	1.8	.8 (.33)	0.8%
10-Ton	-.2	.3	.8	-.2	.8	1.8	.8 (.33)	0.8%

NOTE:

PES - Pessimistic
ML - Most Likely
OPT - Optimistic

* Risk probability that the rating is actually "CON" when the decision maker reached a "PRO" automatic decision.

** Figures in perentheses are standard deviations.

Figure 3

Summary of Rating Values
By Vehicle Weight Class
On A -5 ("Con") to +5 ("Pro) Scale

VEHICLE WEIGHT CLASS	RATING VALUES			WEIGHTED RATING VALUES			AVERAGE RATING VALUE	"RISK"* PROBABILITY RATING
	PES	ML	OPT	PES	ML	OPT		
1/4-Ton	-.2	.3	.7	-.1	.8	1.5	.7 (.27)**	0.5%
1-1/4-Ton	-.2	.3	.7	-.2	.7	1.5	.7 (.29)	0.8%
2-1/2-Ton	-.3	.3	.7	-.4	.7	1.6	.6 (.33)	3.6%
5-Ton	-.2	.3	.8	-.2	.8	1.8	.8 (.33)	0.8%
10-Ton	-.2	.3	.8	-.2	.8	1.8	.8 (.33)	0.8%

NOTE:

PES - Pessimistic
ML - Most Likely
OPT - Optimistic

* Risk probability that the rating is actually "CON" when the decision maker reached a "PRO" automatic decision.

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Figure 3

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