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A STUDY ON THE EFFECT OF GEOMETRY CHANGES ON A VEHICLE'S MILITARY LOAD CLASS

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ABSTRACT

A study was performed to assess the effect of changes to the geometry of the Abrams Tank and Stryker on its Military Load Class (MLC). Using methodology defined per a North Atlantic Treaty Organization (NATO) document, a series of MLC calculations were performed for both vehicles at various weights, using base dimensions as well as modified dimensions, with changes made to either the vehicle's length or width. The calculated MLC and associated Width Correction Factor was recorded at each weight, and the results were analyzed to assess how changes to vehicle length and width affect its MLC. Analysis results are presented in this paper, along with conclusions drawn from the results of this study.

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1. INTRODUCTION

The Military Load Class (MLC) is a number assigned to both military vehicles and bridges using a process defined in [1]. For a military bridge, it represents its official load carrying capacity, resulting from a combination of extensive analysis and testing such as that described in [2]. For military vehicles, it represents the maximum effect it may have on a bridge during a crossing. The MLC provides the user with an easy way to determine if a vehicle can safely cross a bridge or not, ultimately promoting safe use of gap crossing equipment.

More attention has been given to a vehicle's MLC in recent years, resulting from increases in vehicle weight and subsequent concerns about the effects of increased weight on vehicle mobility and the equipment, such as military bridges, that support them. Although [1] states otherwise, a common misconception that currently exists is that a vehicle's MLC is dependent only on its weight, and this misconception results in confusion within the military vehicle community when a vehicle's MLC differs from its weight. Differences between vehicle weight and MLC may result from statics alone but may also be due to the vehicle's geometry. To better illustrate the effects of geometry on a vehicle's MLC, a study was performed to assess the effect of changes to a vehicle's geometry on its MLC. The study focuses on the effects of length and width changes on the MLC of a wheeled and tracked vehicle at various weights. Presented in this paper are the results of this study. Also provided in this paper is an overview of Vehicle Military Load Classification, a description of the vehicles analyzed in the study and the study's analytical procedure.

2. VEHICLE MILITARY LOAD CLASSIFICATION OVERVIEW

Vehicle Military Load Classification is performed using the following calculation procedure established in [1]:

1) Calculate maximum unit bending moment and shear force produced by a vehicle at reference spans ranging from 3.28 feet (1 m) to 328 feet (100 m), inclusive. Unit bending moment is equal to bending moment divided by the span length.
2) Calculate the MLC at each reference span through linear interpolation between the unit bending moment/ shear force values calculated in 1) and unit bending moment/ shear force values for hypothetical vehicles, defined in [1], at each reference span.
3) Determine the Rough MLC, which is the MLC resulting from statics alone. The Rough MLC is equal to the maximum MLC calculated in 2) over all reference spans.
4) Compare the width of the actual vehicle, V_a, to that of the hypothetical vehicle, V_h, representative of the Rough MLC determined in 3). If V_a is less than V_h, calculate a Width Correction Factor (WCF), which accounts for the possible eccentricity effect that results when a vehicle is not centered along the bridge's roadway width during a crossing. The WCF is calculated using the following equation presented in [1]:

$$WCF = 1 + \frac{0.06}{25.4} * (V_h - V_a) \qquad (1)$$

Equation (1) requires the units of the width difference to be in centimeters.
5) Multiply the Rough MLC determined in 3) by the WCF to obtain the corrected MLC.
6) Round the corrected MLC from 5) to the nearest whole number to get the final MLC.

The hypothetical vehicles used in the calculation, with weight and geometry as defined in [1], were created to establish standard tracked and wheeled vehicle representations of various MLCs for design and test purposes.

As the procedure indicates, the calculation of a vehicle's MLC is an extensive process that cannot be generally encompassed in a single equation or parameter. Table 1 lists the information required for both tracked and wheeled vehicles to perform an MLC calculation. As Table 1 indicates, a combination of weight and geometric information is needed to perform the MLC calculation. Tracked vehicles are treated as a uniform distributed load for the calculation, while wheeled vehicles may be treated as either a series of point loads or a series of small distributed loads, with the axle loads being distributed along the tire footprint length.

Table 1: Information Required for MLC Calculations

	Information Required
Tracked	• Total Vehicle Weight • Track Length (length of track in contact with ground) • Outside Track-to-Outside Track Width
Wheeled	• Total Vehicle Weight • Axle Loads • Axle Spacing • Outside Tire-to-Outside Tire Width • Tire Footprint Length (for large wheel calculations)

3. VEHICLES ANALYZED IN STUDY

The study assessed the effects of geometry changes on the MLC of the Abrams Tank and Stryker. Base geometric information for the Abrams and Stryker are provided in Tables 2 and 3, respectively. Abrams dimensions used for the study are similar to that used for the analysis documented in [3], while the Stryker dimensions reflect information that has been used for past MLC calculations for the vehicle. For the Stryker, the vehicle was treated as a series of point loads for all calculations.

Table 2: Base Abrams Geometry for Study

Track Length (in)	Width (in)
180.2	137.01

Table 3: Base Stryker Geometric Information

Width (in)	Axle Spacing (in)		
	1-2	2-3	3-4
102.6	50.4	60.2	50.4

Table 4 provides the axle load distribution, in terms of the percentage of total load, used to calculate axle loads for the Stryker in this study. This axle load distribution was determined by averaging the axle load distributions for the seven most recent MLC calculations completed for the Stryker.

Table 4: Load Distribution for Stryker Axle Load Calculations

Axle Load Distribution (% of total load)			
1	2	3	4
26.24	26.24	23.76	23.76

4. ANALYTICAL PROCEDURE

The analysis was carried out by performing a series of MLC calculations for each vehicle at various weights, starting at a weight of 5 tons. All calculations were performed using the official MLC reference software mandated for use per [1].

Calculations were first performed using the base Abrams and Stryker geometric information provided in Tables 2 and 3, respectively. This not only established a baseline MLC at each weight for which to assess the geometric change effects, but also helped to establish the upper weight range for which the remaining calculations were subsequently performed. The upper weight range for each vehicle in the study was set as the weight at which the MLC of the vehicle at base geometry first exceeds 150. MLC 150 is the highest MLC for which a hypothetical vehicle exists. Extrapolation would be required to determine hypothetical vehicle characteristics for design and testing at any MLC beyond 150. Table 5 provides the upper weight range values established from base geometry MLC calculations.

Table 5: Upper Weight Ranges Used for Analysis

Vehicle	Upper Weight Range (tons)
Abrams	90.7
Stryker	87.5

Once the baseline MLCs were established, the MLC calculations were repeated for each vehicle at the established weight range, first using a series of adjusted width values with length kept at base value, then using a series of adjusted length values with width kept at base value. For this study, 1, 5, and 10-inch changes to the width and length were evaluated to focus the study on the effects of small changes to vehicle geometry. With respect to the Stryker, length changes were applied to the spacing between a single pair of axles instead of spreading the total length change evenly among the overall length between Axles 1 and 4. Combined changes, such as changes to the length and width at the same time and changes to the spacing of multiple pairs of axles, were not assessed at this time. This allowed the focus to remain on effects resulting from a change to a single parameter.

5. RESULTS

5.1. Abrams Tank

Figure 1 shows a plot of the corrected MLC, before rounding, versus vehicle weight for vehicle widths ranging from 10 inches above the base value to 10 inches below the base, while Table 6 presents the maximum deviations from the base value due to each width deviation assessed in the analysis. The MLC versus weight plots were initially linear with a 1:1 slope before becoming non-linear. Width changes did not change the shape of the plot; instead, they shifted the curves left or right once the MLC began to deviate from that resulting from the base dimensions.

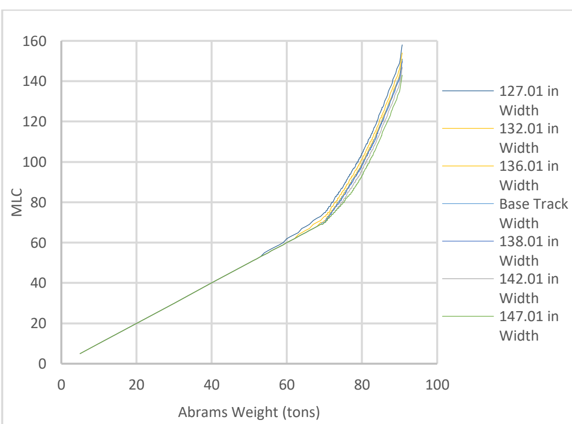

Figure 1: MLC Increases with Decreasing Abrams Width

Table 6: Maximum Deviations Resulting from Abrams Width Changes

Width Deviation from Base (in)	MLC Deviation	WCF Deviation
10	-7.5	-0.06
5	-3.8	-0.03
1	-0.8	-0.01
-1	0.8	0.01
-5	3.8	0.03
-10	7.5	0.06

From the analysis, it was found that even a 1-inch change can result in a deviation in MLC relative to the base value. The further the width deviated from the base value, the greater the deviation in MLC was, with width increases reducing the MLC and width decreases increasing the MLC relative to the base values. The largest magnitude of deviation from the base value resulted from a width change of ±10 inches. The deviation magnitude due to the width change also varied with the weight, with the maximum deviation occurring at the upper weight range value. A further look into the data indicates that the curves are essentially reflections about the base curve, meaning that, for a specific amount of deviation from the base width, the absolute value of MLC deviation is the same at each weight whether you reduce or increase the base width by that amount.

A change also resulted for the WCF. As Figure 2 shows, the effect to the WCF resulting from the width change is similar to that seen with the MLC, where a decrease in width results in a higher width correction factor relative to the base dimensions at the same weight and a width increase results in a lower factor. The maximum magnitude of deviation from the base value resulted from a width change of ±10 inches.

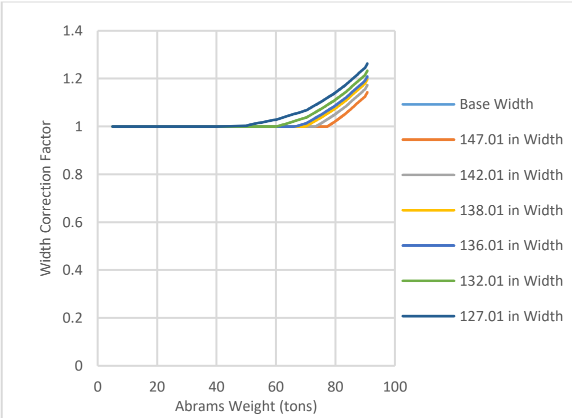

Figure 2: WCF Increases with Decreasing Abrams Width

Figure 3 shows a plot of the corrected MLC versus vehicle weight for track lengths ranging from 10 inches above the base value to 10 inches lower than the base. Table 7 presents the maximum deviations at each length change. Similar to what was observed with the change in width, the magnitude of deviation from the MLC at the base dimensions changed with increasing total vehicle weight. Length reductions increased the MLC, while length increases decreased the MLC relative to the base dimensions.

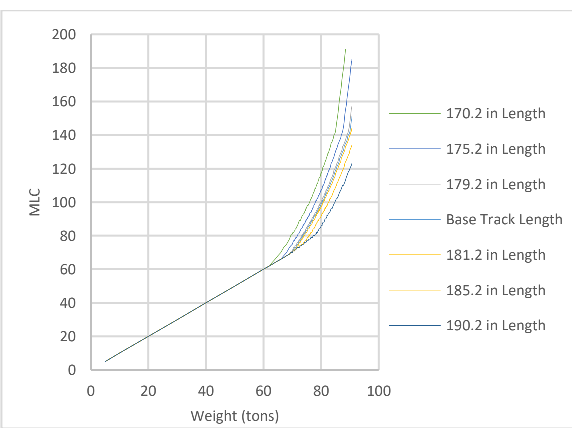

Figure 3: Track Length Changes Result in Greater MLC Changes for Abrams

Table 7: Maximum Deviations Resulting from Abrams Length Changes

Length Deviation from Base (in)	MLC Deviation	WCF Deviation
10	-27.83	-0.06
5	-16.97	-0.04
1	-6.34	-0.01
-1	6.51	0.013
-5	34.38	0.065
-10	55.87	0.109

However, the deviation due to length changes was more significant, as indicated by Table 7 and the increased space between curves in Figure 3 compared to Figure 1. As Table 7 shows, even a change as small as 1 inch to the length can result in a significant change to the MLC. The maximum deviation from the base MLC values resulted from a length decrease of 10 inches. It is noted that the analysis of the effect of a 10 in length decrease on the Abrams MLC was only carried out to a weight of 88.5 tons. At weights beyond 88.5 tons, the rough MLC exceeds 150. A width correction factor is not calculated by the reference software at this point. Any calculated factor would be the result of an extrapolation due to MLC 150 being the highest MLC for which a hypothetical vehicle exists. Therefore, the overall MLC for the Abrams at a 170.2-inch tank length would never exceed the value obtained at 88.5 tons.

Changes were also observed to the WCF due to the change in length, as shown in Figure 4 and Table 7. Similar to the results seen for the change in width, a length decrease resulted in higher width correction factors while a length increase resulted in lower width correction factors relative to the base dimensions. The maximum deviation from the base resulted from a length decrease of 10 inches.

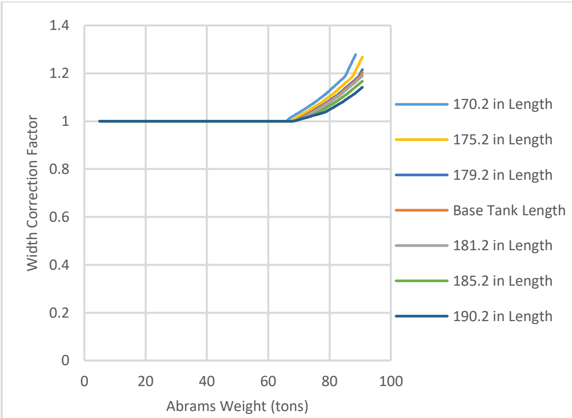

Figure 4: WCF Increases due to Abrams Length Changes

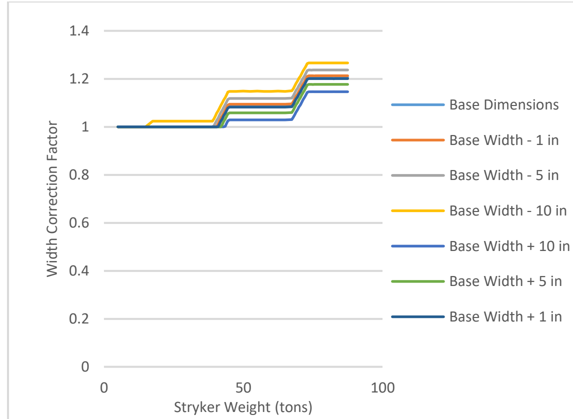

Figure 6: WCF Increases Due to Stryker Width Changes

5.2. Stryker

Figures 5 and 6 show the MLC versus vehicle weight and WCF versus vehicle weight plots for vehicle widths ranging from 10 inches above the base value and 10 inches below the base value. Table 8 shows the maximum MLC and WCF deviations that resulted for each change in width. Similar to the Abrams Tank, the MLC of the Stryker is initially equal to that for the base dimensions, but ultimately shifts to the left or right, depending on if the width was reduced or increased.

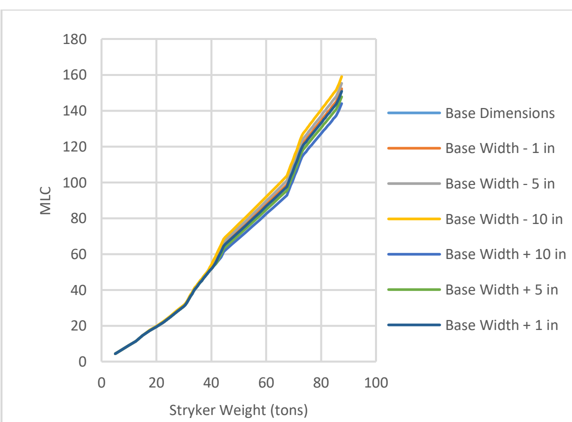

Figure 5: Stryker Width Changes Result in MLC Changes Relative to Base Dimensions

Table 8: Maximum Deviations Resulting from Stryker Width Changes

Width Deviation (in)	MLC Deviation	WCF Deviation
-10	7.5	0.06
-5	3.8	0.03
-1	0.8	0.01
1	-0.8	-0.01
5	-3.8	-0.03
10	-7.5	-0.06

A 1-inch width change resulted in some deviation in MLC relative to the base, but the deviation was more pronounced when width was changed by either 5 or 10 inches. The curves also appear to be reflected about the base curve, meaning that the absolute value of deviation is the same for a particular amount of change from the base width, regardless of whether the base width was increased or decreased. The deviation from the base curve also increased with increasing vehicle weight, with the maximum deviation for each width change occurring at a vehicle weight of 87.5 tons. The maximum deviation magnitude observed at 87.5 tons resulted from a width change of ±10 inches.

Changes to the WCF also resulted from the change in width, with width decreases increasing the WCF and width increases decreasing the WCF relative to that resulting from the base dimensions. The maximum deviation magnitude observed resulted from a width change of ±10 inches. Similar to what was observed for the MLC, the absolute value of deviation from the base WCF values was the same for a particular amount of width deviation, whether width was increased or decreased.

Figures 7 and 8 show the corrected MLC versus vehicle weight and WCF versus vehicle weight plots for various length changes made to the Stryker, while Table 9 provides the maximum deviations observed for changes to the spacing between Axles 1 and 2, Axles 2 and 3 and Axles 3 and 4. All maximum MLC deviations occurred at a weight of 87.5 tons, resulting from a length change of 10 inches. Comparison of Tables 8 and 9 indicate that, in general, length changes resulted in greater change to the MLC relative to the base dimensions than did width changes. Length changes affected the WCF by shifting the weight at which the WCF begins to change with respect to weight. While maximum WCF deviations also resulted from a length change of 10 inches, the weight at which the maximum deviation resulted varied with the axle pair that was changed. Generally maximum WCF deviation occurred at a weight between 70 and 73 tons, in the area where the WCF versus vehicle weight plot has a non-zero slope. These transition points from zero to non-zero slope coincide with changes to the hypothetical wheeled vehicle widths that occur between MLC 50 and 60 and MLC 90 and 100.

Table 9: Maximum Deviations from Base Values due to Stryker Length Changes

Axle Pair	Max Deviation	
	MLC	WCF
1-2	8.9	0.04
2-3	13.6	0.06
3-4	6.8	0.03

6. DISCUSSION

A review of the analytical results due to width changes for the Abrams and Stryker indicate that the primary mechanism for change in the MLC relative to the base dimensions is manipulation of the WCF. Vehicle width changes will not affect the

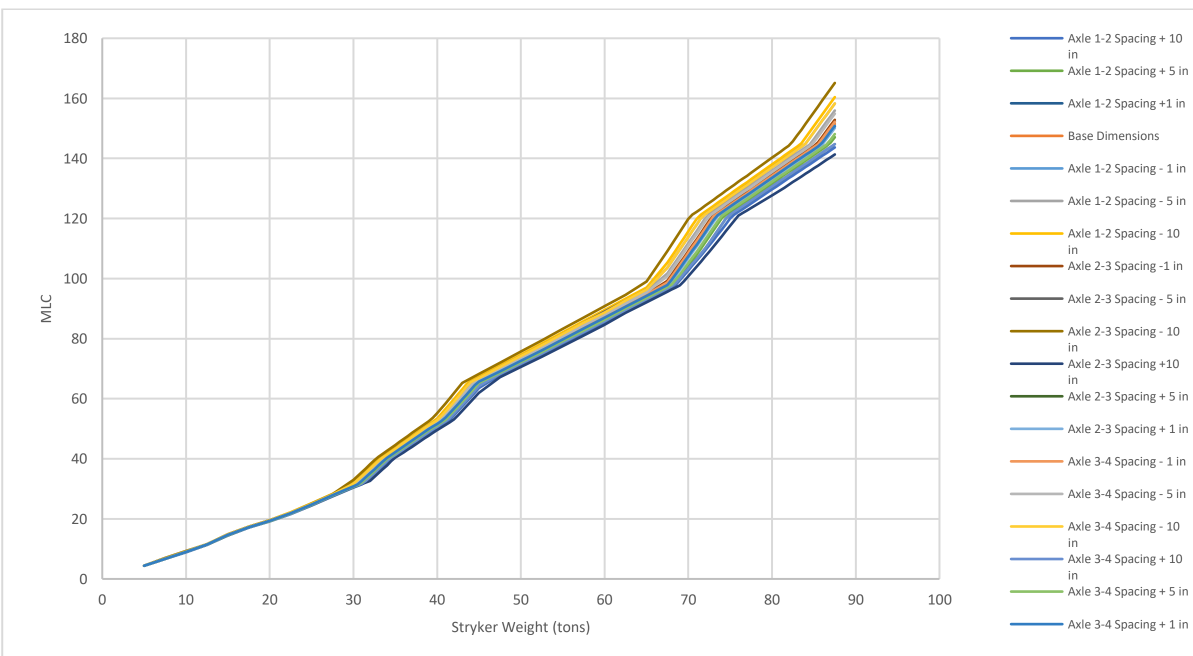

Figure 7: Stryker Length Changes Result in Greater MLC Changes

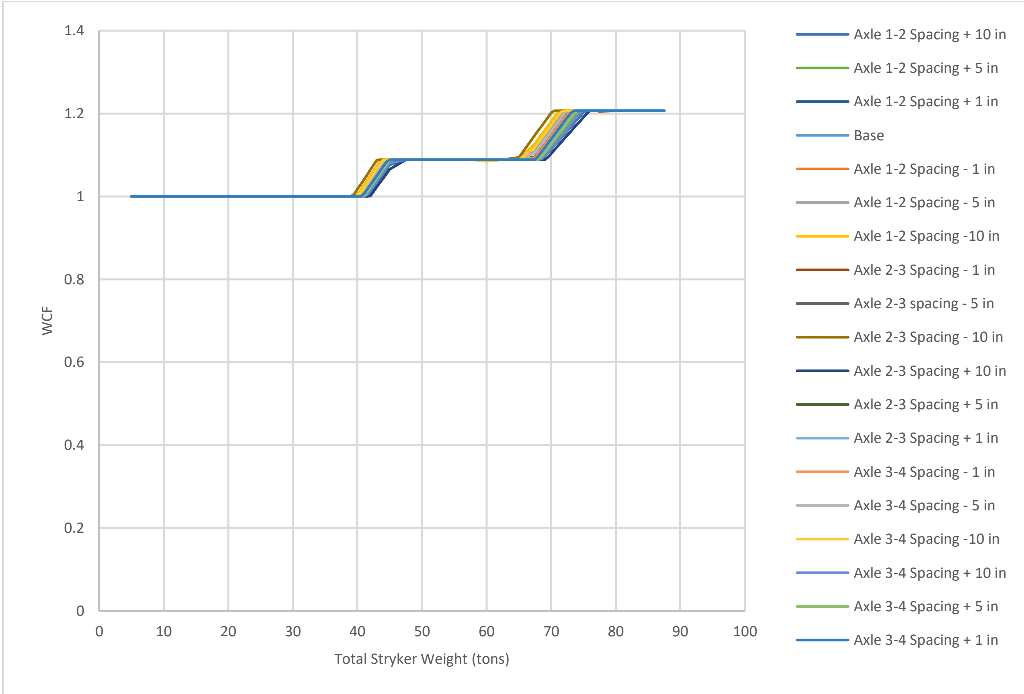

Figure 8: Length Changes Relative to Base Stryker Dimensions Result in Shifts to the WCF Plot

Rough MLC because calculations of bending moment and shear force depend primarily on the location of applied loads along the length of the span. Width changes will, however, affect the weight at which the WCF begins to affect the calculation. Narrowing the vehicle will trigger the WCF at a lighter weight, while widening the vehicle triggers the WCF at a higher weight. This can be seen in both Figures 2 and 6, as the point at which each curve begins to increase from 1 varies with the vehicle width. Width change also affects the magnitude of the WCF. Narrower widths generally resulted in higher WCF values, due to the increased width difference that results when compared to the hypothetical vehicle. The higher WCF magnitudes due to the narrowing of the vehicle will ultimately result in higher vehicle MLCs.

Changes to the length of the vehicle generally had a more significant effect on the MLC. The MLC changes due to changes in length are more apparent when looking at the results for the Abrams versus that of the Stryker. The length change works in multiple ways to affect the MLC. Length changes directly affect the Rough MLC by either contracting or spreading out the load along the length of the bridge. This contracting or spreading out of the load directly affects the bending moment and shear force calculations, thus affecting the unit bending moment and shear force curves used in Step 2 of the MLC calculation procedure. This change to the unit bending moment and shear force curves can result in changes to the hypothetical vehicle curves used for linear interpolation at each span, thus resulting in changes to the Rough MLC. The change in Rough MLC also manipulates the WCF by changing the hypothetical vehicle against which the width comparison is performed. For the Stryker, this resulted in a change to the weight at which the WCF begins to increase but had only a slight effect on the magnitude of the WCF. However, for the Abrams, changes to the Rough MLC resulted in a significant change to the magnitude of the WCF at each weight. An example of this significant change is shown in Table 10 for a vehicle weight of 88.5 tons.

Table 10: Rough MLCs and WCF Values at Various Tank Lengths for Abrams Weight of 88.5 tons

Weight (tons)	Length Deviation from Base (in)	Rough MLC	WCF
88.5	+10	101.4	1.12
	+5	108.2	1.14
	+1	113.9	1.16
	0	115.4	1.17
	-1	116.9	1.17
	-5	127.9	1.21
	-10	149.3	1.28

This change in magnitude likely occurred because the hypothetical tracked vehicle width increases consistently with increases in MLC. This is different from the hypothetical wheeled vehicles, whose width increases only at certain MLC ranges. The consistent increase in hypothetical tracked vehicle width, when combined with a growing Rough MLC and constant Abrams width, can result in significant growth in the WCF and further exacerbation of the MLC. This is the likely reason for the significant change in MLC that resulted from changes in the length of the Abrams tank. This combined Rough MLC/ WCF effect is also a key contributor to the growth in MLC that is currently being seen for the Abrams tank, as vehicle weight is increasing without any subsequent changes in vehicle geometry.

With respect to the Stryker, the data indicates that changes to the spacing between Axles 2 and 3 result in the greatest change to the MLC and WCF relative to the values resulting at the base dimensions. Further investigation is required to determine why this is the case. It is noted that the longitudinal center of gravity for the vehicle, calculated using the base dimensions and axle load distribution provided in Tables 3 and 4, lies between Axles 2 and 3. Changes that occur to the longitudinal center of gravity can affect the location of the vehicle along the length of the bridge for maximum bending moment. However, this aspect of the calculation was not examined in detail at this time. Further studies into the role that the center of gravity location has on the results are planned, in addition to further studies looking into the effect of combinations of changes, such as changes to both length and width or changes to spacing between multiple axle pairs.

The study highlights the effect that small changes to a vehicle's geometry may have on a vehicle's MLC. Changes to the MLC, though small, did occur with 1-inch geometry changes. Significant changes also resulted from 5 and 10-inch changes to the geometry. This helps to further illustrate the effect of vehicle geometry on a vehicle's MLC and, subsequently, a bridge's MLC, while helping to improve understanding of Military Load Classification as a whole.

7. CONCLUSION

A study was performed to examine the effects of small geometry changes on the MLC of a wheeled and tracked vehicle at various weights. The results of the study indicate that changes as small as 1 inch to either the vehicle's width or length can affect its MLC, and changes of 5 or 10 inches may have significant effects on a vehicle's MLC. Changes to length, from a general sense, had a greater effect on the MLC than changes to width due to its effect on the Rough MLC and effect that changes to the Rough MLC have on the WCF. Further studies are planned to examine the effects of geometry changes to military vehicles further, namely the effect of the longitudinal center of gravity location for wheeled vehicles and changes to multiple geometric parameters at the same time.

8. REFERENCES

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[2] B. Sia, A. Rudow, and E. Townsend, *Trilateral Design and Test Code for Military Bridging and Gap-Crossing Equipment*. US ARMY CCDC GVSC (FORMERLY TARDEC) WARREN United States, 2019.

[3] B. Sia, Abrams and Heavy Equipment Transporter Bridge Crossing Capability Analysis, US ARMY TARDEC, Warren, 2018.