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Evaluation and benchmark of high-performance computer platforms for automotive crashworthiness simulation

C. –D. Kan, A. Eskandarian, & J. Mader
FHWA/NHTSA National Crash Analysis Center, George Washington University, Virginia Campus, 20101 Academic Way, Ashburn, Virginia 20147, USA

Abstract

This paper reports the evaluation and benchmark results of vehicle crash simulations using high-performance computer systems, which is well suited for addressing some of the above-mentioned computational and user requirements. In this paper, two large size vehicle models are used in this benchmark study for a typical industrial standard crashworthiness application. The performance related issue including parallelism, reliability, and repeatability of the simulation results are addressed. The results of porting of MPP version of the commercial crash code, LS-DYNA, are also included in this paper.

Introduction

Today, computer simulations using finite element (FE) methods are routinely used by engineers for virtually all modes of crashworthiness related analyses, ranging from vehicle structural design, occupant protection assessment, as well as roadside hardware evaluation. At the same time, the size and complexity of finite element models used in these simulations has been increased exponentially over the past five years. In order to have reasonable turn-around time to solve crash models, it requires availability of high-performance computer platforms that are low-cost and easy to use [1-7]. While traditional vector supercomputer architectures have continued to improve in performance, the growth in the performance of microprocessors has proceeded at a far more rapid rate. The price-performance ratio of vector supercomputers lags far behind than that of today's microprocessor machines. However, individual microprocessors do not

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have the processing power to solve today's largest numerical simulation problems. Massively Parallel Processing (MPP) architecture computers connect a large number of small, relatively inexpensive "mass market" processors together, and use the entire bank of processors together to solve a problem. This approach results in machines with aggregate CPU, I/O and memory bandwidth performance often exceeding the performance of a traditional vector supercomputer, but at a dramatically reduced cost.

High-performance MPP computer systems have been available on the market since earlier 1990, but have yet to replace vector systems or even shear memory parallel (SMP) high performance systems as the workhorse in large production computer facilities. While the use of MPP has been increased rapidly during the fast three years, there are a number of factors that have been resolved to the successful deployment of MPP systems in production environments for crash codes. Early commercial MPP platforms encountered a number of technical problems (both software and hardware related) that resulted in negative experiences at computer centers that chose to be early adopters of MPP technology. The conversion of existing vector codes to a form that runs efficiently on and MPP system has proven an enormous task - one of similar complexity to re-writing the basic algorithms used in the codes. This has resulted in the introduction of new 'bugs' in these codes. These codes need to be absolutely reliable, and in their original serial/vector form, are considered reliable. The result of experiences with MPP code accuracy has been the desire to carefully evaluate and re-validate the code to ensure that it is behaving identically to the vector code. Additionally, the operating system and user environments of MPP machines are substantially different from those of traditional systems. While batch processing a typical workload on a scalar system is relatively straightforward, it is somewhat more complex task for a MPP system. This is due to the fact that how to arrange the workload becomes more complex when the additional freedom of being able to run problems on different numbers of processors is added. Particularly, different types of jobs on MPP system react differently to running on larger or smaller numbers of processors.

This paper reviews the state-of-the-art of MPP nonlinear finite element code, LS-DYNA, a widely used crash code for automotive industries, and its applications. The results of case studies for high-performance computer system are presented. The issues of reliability, consistency, and repeatability of MPP version of a nonlinear finite element code, as well as the comparison of accuracy with SMP version of the same code are discussed. The effectiveness and benefit of using MPP are demonstrated through case studies that also included in this paper.

MPP code status

Serial versions of the crash code LS-DYNA used for this study are SGI Power Origin 2000 platform as well as the HP V-Class. LS-DYNA has two parallel versions, a Symmetric Multiprocessor (SMP) version which runs on shared-memory machines such as multiprocessor Cray and SGI platforms (this version

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is also sometimes referred to as the vector parallel version or the data parallel version), and MPP version which runs on distributed memory massively parallel platforms. SMP Parallel version of LS-DYNA uses same algorithms as serial LS-DYNA code, and therefore offers a high degree of assurance that results of parallel runs are identical to the results generated by the serial code. Because some parallel operations such as reduction operations are inherently non-deterministic when implemented in parallel, an option is provided in the SMP parallel version of LS-DYNA where operations such as reductions are performed in a deterministic fashion. This option (the default) results in a small performance penalty, but ensures identical results every time the code is run. The MPP Parallel version of LS-DYNA uses a domain-decomposition approach based on message passing to break a crash problem into smaller parts, and then perform the calculations on a distributed set of processors. Both the dynamics and the automatic contact detection are performed in parallel.
The current MPP release of LS-DYNA is version 950/960, which is the same as the serial code. The MPP code is available for Cray T3E, the IBM SP-2 and the HP Exemplar/V-Class/K-Class Systems and SGI Power Challenge and Origin 2000 systems. The SMP parallel code, version 950 is available for shared memory systems including vector Cray (T-90, C-90 and J-90), the HP Exemplar, V-Class, K-Class, and SMP workstations, and the SGI Power Challenge and Origin 2000. Ports to new platforms can be made relatively easily, because LS-DYNA supports several common libraries for communications, including PVM and MPI. Porting to a different hardware platform merely requires re-compiling and linking the software using the PVM or MPI libraries available for that system. Assuming the PVM or MPI libraries are ported correctly, the code requires little if any modification to run.

Simulation cases and finite element models

Simulation cases – Two simulation cases are used for the evaluation of the performance of MPP version of LS-DYNA code. The first case involves the simulation of vehicle-to-vehicle offset impact while the second case is the simulation of vehicle-to-roadside hardware impact.

Finite element models – The finite element models used in the first simulation case is the Chevy C-1500 pickup truck and Dodge Neon compact passenger car. Both models were developed at the FHWA/NTSA National Crash Analysis Center at the George Washington University [8,9]. Since these models, particularly the Neon model were developed for multiple impact application purposes, greater efforts were devoted to include all the geometric detail of the vehicle into the finite element models. The information of this finite element model is summarized in Tables 1 and 2 for Chevy C-1500 and Dodge Neon, respectively. Figure 1 shows the isometric views of these vehicle models individually while Figure 2 shows both vehicle models in the offset frontal impact configuration.

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Table 1. FEM Information of C-1500 Pickup

Parts	217
Nodes	61,304
Solid Element	3,358
Beam Element	184
Shell Element	50,428

Table 2. FEM Information of Neon

Part	323
Nodes	285,634
Shell Element	267,847
Beam Element	67
Solid Element	2,860

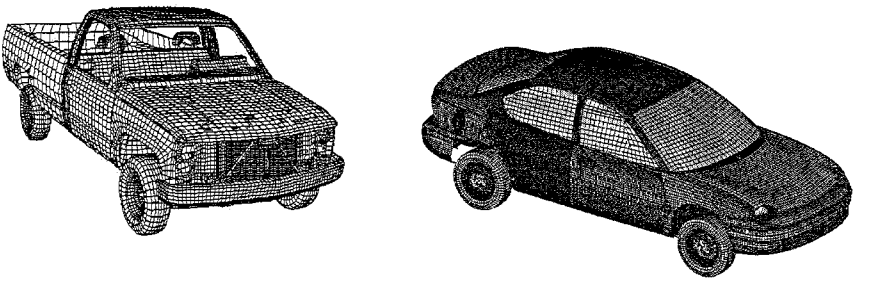


Figure 1. Isometric View of the Chevy C-1500 and Neon Finite Element Models

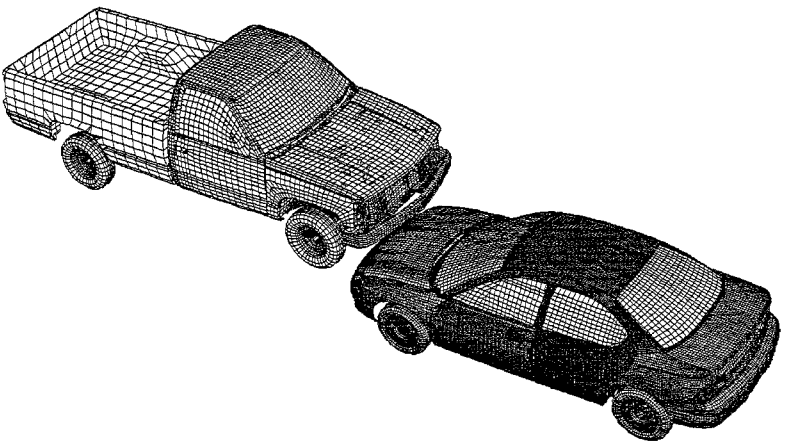


Figure 2. Chevy-to-Neon Frontal Offset Impact Model

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The second simulation case involves the vehicle impacting to a roadside hardware, a 5-foot height breakaway sigh support. The vehicle model used in this case is the Dodge Caravan. The finite element model of the vehicle was also developed at NCAC for the purpose of multiple impact applications [10]. The finite element mesh sizes were kept uniform throughout the entire vehicle. The average mesh size in this model was maintained at about 12 – 15mm. The finite element model information is summarized in Table 3. Figure 3 shows the Dodge Caravan vehicle model.

Table 3. FEM Information of Caravan

Parts	539
Nodes	381835
Number of shells elements	330,582
Number of beam elements	130
Number of solid elements	6,253

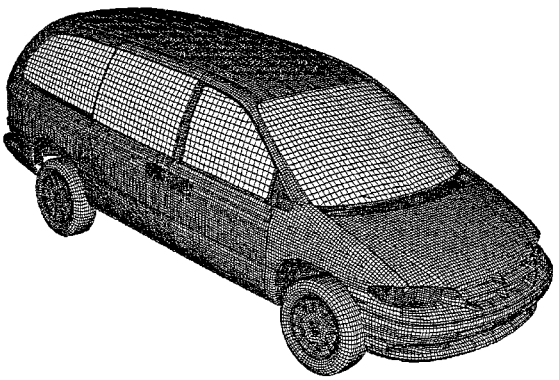


Figure 3. Isometric view of the Neon finite Element Model

Simulation

Current production version of MPP LS-DYNA is used to carry out these two simulation cases on a Hewlett-Packard V class (V2500) computer system. Figures 4 and 5 illustrate the initial and deformed states of the simulation for these two cases of simulation, respectively. The first case was simulated for 150 milliseconds of impact event while the second case for 50 milliseconds. Figures 4 and 5 illustrated the vehicle models in the two simulation cases at their states and deformed states, respectively.

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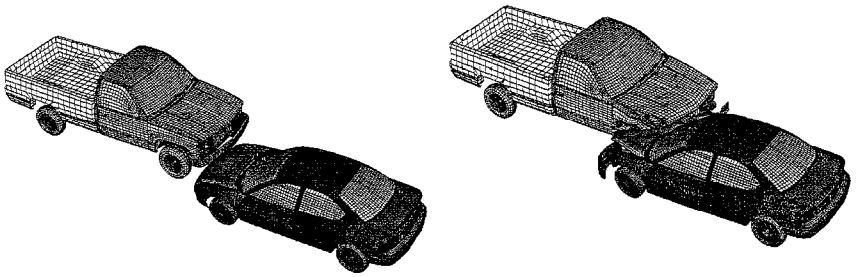


Figure 4. Initial and Deformed States for Case 1 Simulation

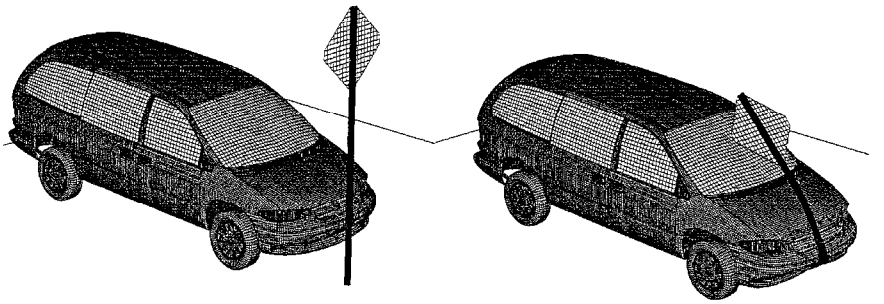


Figure 5. Initial and Deformed States for Case 2 Simulation

Discussion of simulation results

Performance of MPP – Simulation runs using MPP versions with 1, 2, 3, 4, 5, 6, 7, and 8 CPUs were carried out on the 8-CPU HP V2500. Figures 6 and 7 shows the comparison of CPU timings of using different number of CPUs, respectively. The scaling of using different number of CPUs is plotted in Figure 8 and 9 for these two cases, respectively. In both simulation cases, it can be observed that the scalability of the CPU timing improves as number of CPU is increased. It is also interesting to note that for second case, the scalability was rather flat between two to five CPUs but started to improve the number of CPU exceeds five.

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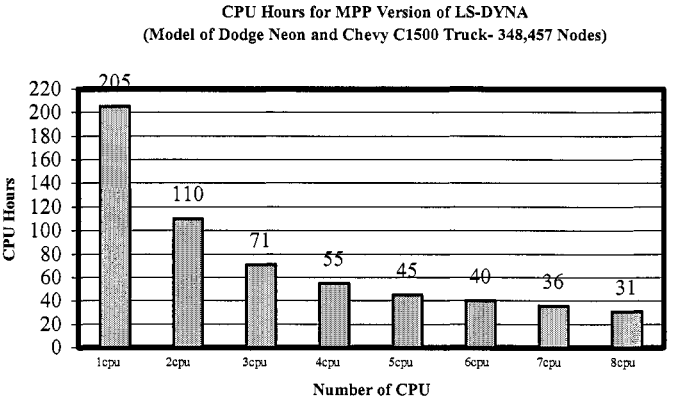


Figure 6.Comparison of CPU Timing for Case 1

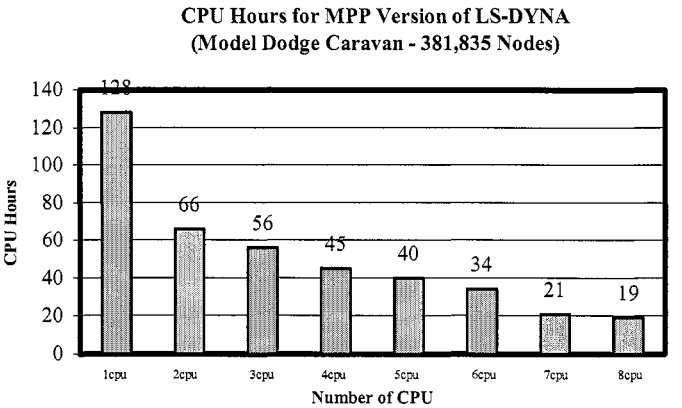


Figure 7. Comparison of CPU Timing for Case 2

While the maximum number of CPU used in this study is limited to eight it is expected that the scalability will further improve with larger number of CPUs based on our previous findings. Compared with previous studies, it is observed that the performance in terms scalability improved with the models used in this study. This is expected since MPP version should scale better for larger size models used in this study (380,000 elements) versus previous study (270,000 and 52,000 elements). It should be interesting to ascertain the speedup of MPP version beyond eight CPUs, which is not available at the time this paper is prepared.

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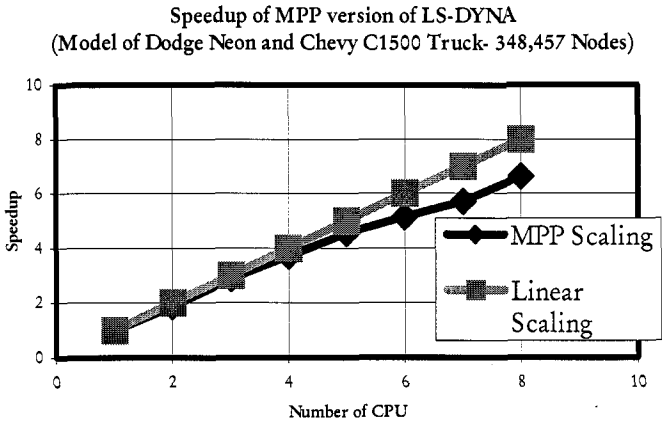


Figure 8. Scaling of MPP 940 for Case 1

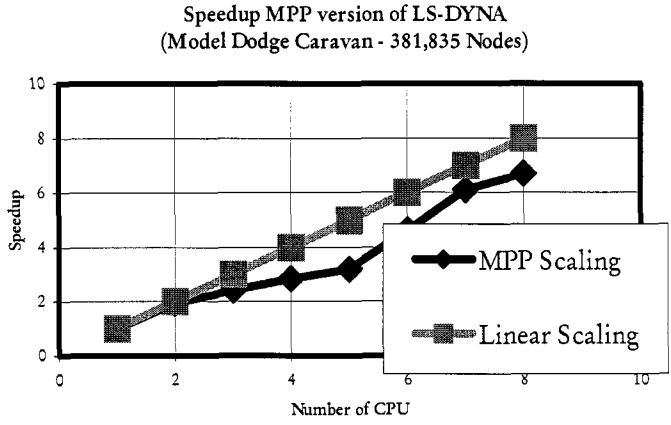


Figure 9. Scaling of MPP 940 for Case 1

Accuracy, Consistency and Reliability – Repeatability of the MPP version has been improved over the past few years as also observed in this study. The comparison of certain acceleration results using different number of processors for MPP version showed relatively lower consistency. While improvement has been made in the past few years on consistency issue, this still remains to be a critical issue that needs to be resolved by software developers.

Comparison between MPP and SMP – Although direct comparison between MPP and SMP versions of the code is not included in this paper, several runs

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using SMP were carried out. It was observed that when smaller number of CPUs is used the SMP version still outperforms the MPP version, which is consistent with the previous findings. However, MPP version offers better performance in terms of CPUs timing and scalability when more that six CPUs are used.

Summary

The MPP versions of LS-DYNA are used for two case study of simulation of crash/impact events up to 150 milliseconds. Large size finite element vehicle models, up to 380,000, were used in both cases. The performance of MPP version is evaluated in terms of CPU timings, scaling, consistency and reliability.

While performance of the current SMP version showed significant improvement in terms of CPU timing and scaling, MPP version has shown maturity in terms of consistency and reliability. When same large numbers of CPUs are used, MPP version out perform SMP version in terms of CPUs time and scaling. However, the fact that MPP is running considerably slower than SMP, when the number of CPUs is small, indicates additional improvements are still needed.

References

[1] Bedewi, N.E., Kan, C.D., Summers, S., and Ragland, C., "Evaluation of Car-to-Car Frontal Offset Impact Finite Element Models Using Full Scale Crash Data," Issues in Automotive safety Technology, SAE Publication SP-1072, pp 212-219, February, 1995

[2] Miller, L., Bedewi, N., and Chu, R., "Performance Benchmarking of LS-DYNA3D for Vehicle Impact Simulation on the Silicon Graphics POWER CHALLENGE" Presented at the High Performance Computing Asia 95, October 1995, Taiwan.

[3] Kan, C.D., Lin, Y.Y., and Hollamby, R. "Reliability of the MPP Version of LS-DYNA and Its Comparison with SMP Version, Interim Results," The LSTC-LSDYNA UK User Conference, July 1998, London, England.

[4] Lin, Y.Y., Kan, C.D., and Hollamby, R. "The Performance of MPP LS-DYNA on Crash Simulation," The 5th International LS-DYNA Users Conference, September 1998, Detroit, MI

[5] Kan, C.D., Lin, Y.Y., and Hollamby, R., "Evaluation of MPP Version of LS-DYNA and its Comparison with the SMP Version," Proceedings of Fifth International LS-DYNA3D Conference, Detroit, MI, section N, paper #2, September 1998.

[6] Lin, Y.Y., and Kan, C.D., "Crash Simulation on Parallel Multiprocessors," Proceedings of Fifth International LS-DYNA3D Conference, Detroit, MI, section N, paper#3, September 1998.

[7] Kan, C.D. and Lin, Y.Y., "Evaluation of High Performance Computer Systems Using A Large Finite Element Model," Proceedings of the Second European LS-DYNA Users Conference 1999, section G, paper #4, pp G39-G46, Gothenburg, Sweden, June 1999

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ISBN 1-85312-924-0

[8] Zaouk, A. K, "A Procedure for the Development and Validation of a Detailed Vehicle Finite Element Model," (1998) Master's Thesis, The George Washington University, Washington, DC.

[9] Zaouk, A., Bedewi, N.E., Kan, C.D., and Marzougui, D. "Validation of a Non-linear Finite Element Vehicle Model Using Multiple Impact Data," 1996 ASME Winter Annual Congress and Exposition, Atlanta, GA. November 1996, ASME Publication: Crashworthiness and Occupant Protection in Transportation Systems, AMD-Vol. 218, pp.91-106.

[10] Monclus-Gonzalez, J., Kan, C.D., and Bedewi, N.E. "Versatility and Limitations of a Fully Detailed Finite Element Model of a 1997 Dodge Grand Caravan for Crashworthiness Applications," Accepted for publication in 2000 SAE Congress, March 6-9, 2000, Detroit, MI.