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Virtual Prototype Manufacturing of a Miniature Munition System

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Abstract

Warfighters are in need of precision strike and/or small payload type weapons commonly referred to as miniature munitions in order to fill a current gap with respect to surface to surface missiles. Manufacturing of miniature munitions is difficult due to the small size or miniaturization of missile components. Servos, electric motors, electronic boards, metallic/non-metallic components, energetics, etc. can be challenging in order to manufacture prototypes let alone significant quantities required to perform operational/demonstrational tests. In order to mitigate risk, understand the manufacturing process(es), and optimize assembly procedures, a virtual prototype modeling tool and methodology is in development for manufacturing and assembly of miniature munitions. Figure 1. is an illustrative example of a process model that depicts the inputs/outputs and the assembly line in a pictorial fashion. Low cost manufacturing, automation processes, and streamlining assembly procedures/manufacturing cells are targeted in this virtual prototype development. Scenario based planning and predictive analysis can be achieved in order to evaluate critical paths, bottlenecks, and production volumes can be directly derived as outputs from this virtual prototype. In order to reduce cycle times and ensure that product can be quickly and efficiently produced, it is important to analyze the assembly procedures of the individual systems within the overall munitions (seeker, warhead, rocket motor, servos, etc.) as well as the munitions as a whole. Process optimization (manufacturing line/assembly procedures) can identify processes that are complex or that require significant times which can then be evaluated for cycle time reduction. When drawing conclusions from this modeling tool one should proceed with caution and verify assumptions and constraints. One can imagine that the tool will provide perfect optimization and that the "tool rules" when it comes to understanding production volumes, however thought should be applied in order to not derive flawed assumptions or that the tool is always right. This paper will provide a detailed approach and analysis for establishing a predictive tool to evaluate miniature munitions with the focus on a low cost, reliability, quality, and a highly manufacturable miniature munitions.

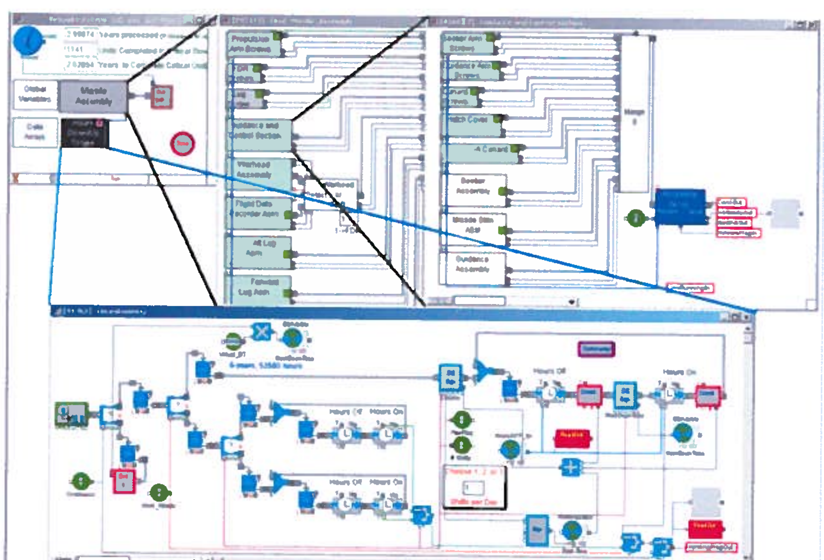

Figure 1. Virtual Prototype pictorial display. Illustrative example of product output from process modeling tool.

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Warfighters are in need of precision strike and/or small payload type weapons commonly referred to as miniature munitions in order to fill a current gap with respect to surface to surface missiles. Manufacturing of miniature munitions is difficult due to the small size or miniaturization of missile components. Servos, electric motors, electronic boards, metallic/non-metallic components. energetics, etc. can be challenging in order to manufacture prototypes let alone significant quantities required to perform operational/demonstrational tests. In order to mitigate risk, understand the manufacturing process(es), and optimize assembly procedures, a virtual prototype modeling tool and methodology is in development for manufacturing and assembly of miniature munitions. Figure 1. is an illustrative example of a process model that depicts the inputs/outputs and the assembly line in a pictorial fashion. Low cost manufacturing, automation processes, and streamlining assembly procedures/manufacturing cells are targeted in this virtual prototype development. Scenario based planning and predictive analysis can be achieved in order to evaluate critical paths, bottlenecks, and production volumes can be directly derived as outputs from this virtual prototype. In order to reduce cycle times and ensure that product can be quickly and efficiently produced. it is important to analyze the assembly procedures of the individual systems within the overall munitions (seeker, warhead, rocket motor. servos, etc.) as well as the munitions as a whole. Process optimization (manufacturing line/assembly procedures) can identify processes that are complex or that require significant times which can then be evaluated for cycle time reduction. When drawing conclusions from this modeling tool one should proceed with caution and verify assumptions and constraints. One can imagine that the tool will provide perfect optimization and that the "tool rules" when it comes to understanding production volumes however thought should be applied in order to not derive flawed assumptions or that the tool is always right. This paper will provide a detailed approach and analysis for establishing a predictive tool to evaluate miniature munitions with the focus on a low cost, reliability, quality, and a highly manufacturable miniature munitions.

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Nomenclature

MM	=	Miniature Munitions
MMS	=	Miniature Munitions System
AUR	=	All Up Round
G&C	=	Guidance and Control
ESAD	=	Electronic Safe and Arming Device
VP	=	Virtual Prototype
COTS	=	Commercial Off The Shelf
NAWC-WD	=	Naval Air Warfare Center, Weapons Division
WPD	=	Weapons Prototype Division, NAWC-WD
DFM	=	Design for Manufacturing
DT/OT	=	Demonstrational Test/Operational Test
GUI	=	Graphical User Interface

I. Introduction

MINIATURE munitions (MM) are becoming more and more desired due to precision kill and low collateral damage requirements. NAWC-WD, China Lake has several conceptual programs currently in development in order to fill the needs of warfighters and/or gaps that currently exist in the weapons community. As a result of this miniature munitions development, manufacturing and concurrent engineering of these systems has evolved to some extent organically. Rapid delivery to the fleet of conceptual/ prototype weapons has been proposed in many instances. As a direct result of the likelihood of miniature munitions being fielded rapidly, it has been established that manufacturing of these items will need to occur organically and in rapid fashion. In order to fill this need of rapid manufacturing, a tool has been developed to evaluate all the necessary elements of manufacturing as it pertains to a generic MM system. The current tool has been developed, prototyped, and several experimental runs have been completed using the tool. Overall, the tool requires further development and refinement nevertheless it can be used to analyze all aspects of the manufacturing process.

II. Virtual Prototype

A. Definition - What is a Virtual Prototype (VP)?

Depending upon who you talk to, one will likely get a wide array of answers. Nevertheless, it is important to define, for the purposes of this paper, what a VP is. A VP is essentially a computer generated model/simulation in which one can derive some form of useful information, and in this case, it pertains to manufacturing of a miniature munition system (MMS).

B. Assumptions and Constraints

In order to establish a baseline for the virtual prototype, ground rules or initial assumptions and constraints needed to be established. Such items were established for the initial version of the prototype:

1. Sufficient manpower exists in order to facilitate the manufacturing/assembly within the prototype, i.e. there is no manpower shortage, absenteeism, or lack of skilled/unskilled labors.
2. Work is completed within a single shift (8 hour day), however, this can be easily modified to adapt to multiple shifts (i.e. traditional second and third shifts, two twelve hours shifts, etc.).
3. If a given worker is transitioning from one task to another, no added cost or time are incurred
4. 100% efficiency for each worker is assumed initially. If in fact, there is substantial wait time for a skilled position or inherent setup, this can be varied to whatever percentage is anticipated and then used to calculate the corresponding cycle time.
5. Both Linear/Parallel processing can occur depending upon assembly requirements. The programmer must establish the appropriate rules in which components/assemblies can be manufactured and in what fashion they will contribute to the VP.
6. External manufacturer's (suppliers) information is input and a contributor to the VP/timeline of events.

7. All components are assumed to be compliant, tested, verified. Essentially there is no contributor to scrap, rejected hardware/assemblies, or waste stream. Future versions will have provisions for the contribution of scrap, non-compliant hardware, etc.

The utility of the virtual prototype allows the programmer/engineer to modify any assumptions/constraint as long as it does not violate the laws of physics/universal constants such as a 24 hour day, etc. As with any model, the assumptions and constraints are the keys to ensuring the VP will properly represent what the user inputs and what the customer desires in terms of output.

C. Architecture

In order to more completely characterize a MMS, it was determined to create a "skeleton" or generic architecture in which a generic MMS would be characterized by (i.e. parent assemblies and corresponding sub-assemblies). This "skeleton" or generic architecture common to a MMS are:

- All Up Round (AUR) Missile Assembly (Top Level)
    - Guidance & Control (G&C) Assembly
        - Seeker Assembly
        - Servo/Control Assembly
        - Guidance Electronics Assembly(s)
    - Ordnance Section
        - Warhead Assembly
        - Fuze/ESAD Assembly
    - Propulsion Assembly
        - Rocket Motor Assembly
        - Igniter Assembly
    - Software

This boilerplate hierarchy enables the framework for the virtual prototype. This framework exists in order to be "mass customizable" when it comes to adapting a given miniature munitions system. In other words, the specifics for each system will likely conform to a variant of the "skeleton" and can be tailored/customized for each system based upon the specific items contained within each system.

Once the architecture and assemblies are created in the virtual prototype any pertinent or desired data can be input, tracked, and then used as predictive/forecasting/futuring data. The overall goal for predictions in the model are:

- Cost
    - Individual Component Cost
    - Assembly Cost
    - Touch Labor Cost
    - Total Cost
- Schedule
    - Long-lead Items
    - Cycle Times
    - Assembly Times
- Production Line Information
    - Line Setup (Order of Operations)
    - Dependent/Independent Operations/Steps
    - Optimization
    - Bottlenecks
    - Predictive Analysis
        - Production Line Reconfiguration
        - Scenario/Situational Analysis
        - Futuring Analysis
- Drawing Modifications/Revisions
- Effect of Changes to:
    - Missile Design/Revisions

- Production Line
- Sources of Supply
- Insertion of Technology

D. Creating the Manufacturing Line or Cell

As with any manufacturing process, a comprehensive series of items need to be considered and input in specific fashion. For example, the following items are variables within the VP:

- Purchased items - items manufactured by subcontractors or commercial off the shelf (COTS) items which are economically feasible to purchase due to commercial availability
- Manufactured items - items which are organically manufactured by the assembly cell that can be controlled by the prime
- Mechanical components are assumed to be complete in terms of compliance to the drawing requirements
    - Dimensionally correct components
    - Finished components - plated, painted, coated, etc.
- Electronic components are assumed to be one of the following
    - Individual electronic components kitted for population
    - Circuit boards which are unpopulated
    - Circuit boards that are populated
    - Tested and verified complete circuit boards or components
- Kitted items - items that are called out in assemblies or subassemblies which are required to complete the specific assembly. Essentially these are items which are coalesced into an aggregated form in order to feed the specific subassembly
- Consumable/Perishable Items
- Tooling - both permanent and perishable tooling required to facilitate/manufacture/assemble individual components or assemblies
- Touch Labor Cells
- Robotic Assembly cells

Current and future capabilities for the WPD were incorporated specifically into the VP. Such items as robotic assembly and "lights-out" manufacturing cells were assumed where appropriate. In most cases for the initial runs in the prototype, manufacturing times, assembly cycle times, external vendor cycle times were known and input into the model in order to validate current predictions of missile assembly.

E. Software

The specific software used to create the VP is Extend. Extend is a software package that allows for time discrete event modeling or continuous modeling for simulations and/or analysis. A variety of other systems were evaluated in order to host the VP, however due to internal IT provisions/constraints, the timeline of utilizing other systems was not feasible. In order to utilize a software package, it must be BETA tested and approved via the DATUMS process (a sort of vetting, functionality, and security testing). In addition to gaining approval to the use of software on Navy IT systems, the cost of the software can be substantive for the packages evaluated. Due to the short timeframe and budget, using existing/approved software allowed for the project to progress at minimal cost and within the allotted timeframe. As the VP progresses, it is possible to incorporate or bridge to other manufacturing software packages which can compliment or host the VP in a more efficient manner. Some of the software packages that were investigated but not chosen due to IT constraints are:

- ARENA
- PMCorp Software
    - WITNESS
    - SIMUL8
    - AUTOMOD
- Siemens Software
    - TECNOMATIX
    - TEAM CENTER VISUALIZATION

F. Results

The VP was created, data input, and simulations/scenarios were performed for a MMS in development at NAWC, China Lake. The VP was tested with a variety of basic assumptions and constraints which can be modified to suit the actual scenario. Cycle times, costs, subassembly/assembly times were established in order to derive tangible data regarding the MMS evaluated. While the tool is still in a development stage, it has proven reliable to validate existing data sets and current beliefs of the MMS evaluated. The data derived from the VP will be used directly should the MMS be chosen to either manufacture a short run of DT/OT rounds and/or a fleet readiness/rapid reaction quantity for employment in theater. Further, the tool was helpful in identifying potential bottlenecks, supply chain issues, and both cost and schedule concerns.

The tangible outputs of the VP for the MM system of interest are:

1. Established architecture and drawing package validation
    a. Mechanical
    b. Electronic
    c. Assemblies
2. Established processes/procedures for building missiles
3. Established following analyses for:
    a. Cost
    b. Cycle Time (Individual & Total)
    c. MMS Throughput
    d. Supply Chain Issues
    e. Surge Capabilities
4. Identification of Critical Paths and/or Bottlenecks in the production line
5. Identification of Limitations and Constraints with respect to the current MMS design
6. Identification of Limitations and Constraints with respect to Supply Chain Issues
    a. Raw Material Availability
    b. COTS availability & production capacity of subcontractors
    c. Saturation Levels
    d. Proprietary components/assemblies contained within the MMS
    e. High Cost/High Lead Time materials or components

G. Future Work

Further development of the virtual prototype will occur depending upon funding and current/future projects which might find utility with the virtual prototype. Ideally the virtual prototype will become a useful tool for not only production environments but also for determining production volumes, cost, schedules, etc. With enough time and programming expertise, a GUI type interface can be designed in order to allow non-technical users to input data or produce rudimentary simulations for quick analysis. It is also envisioned that the virtual prototype will include a module that will allow for plant footprints and even a "virtual walk-thru" of the plant to add visual and enhance the prototypes capabilities. As with any manufacturing process, a proper design for manufacturability (DFM) needs to be conducted on the pertinent system prior to initiating a production cell. The VP allows for one to evaluate current methodologies and identify long lead items, long cycle times for assembly, etc. which give "low-hanging fruit" in order for a proper DFM to be initiated.

Tying the VP to an inventory management system would be considered to be a likely follow-on. In essence the VP would correlate current inventories, future deliveries, etc. and be able to predict a variety of possible outcomes for manufacturing of MM systems. Questions such as could likely be answered:

- When will I run out of parts?
- Will I run out of parts?
- What are long lead items?
- Which items are cost drivers?
- Etc.

Provisions for quality assurance, defect or rejected hardware, scrap rate, etc. can be included in future versions. Initially the model assumes 100% acceptance but reality dictates a given scrap/defect rate for any process of manufacturing or assembly. In addition, rework and/or repair can be incorporated into the VP in order to determine the respective cycle time and costs associated with those processes. Ideally, it is envisioned that the VP will be able to predict or determine feasibility of rework/repair or to truly scrap and remove the hardware in terms of cost/schedule decision points. Vendor on-time delivery, approximate scrap rate/rate of rejected hardware/assemblies, etc. will be a potential output if sufficient data is collected from a "real" production environment.

III. Conclusion

The VP has been established and has been utilized to conduct several analyses relative to MM systems. As a result, it has been determined to be a valuable tool when it comes to planning operations pertaining to manufacturing of MM systems. The predictive analysis/futuring of possible outcomes based upon the assumptions and constraints has proven to be a valued asset when it comes to possible MMS production. Further, there are several salient conclusions that need to be recognized when it comes to the tool:

1. The VP does not always rule. Keep in mind, the VP can be wrong and conclusions drawn from the VP should be carefully examined and validated with respect to reality if at all possible.
2. Application/Interpretation of the model must be done carefully as to not misconstrue actual production rates/numbers.
3. The VP is only as good as the assumptions and constraints established. Further, the old adage "garbage in – garbage out" applies. The use of robust data will yield a proper output.
4. Reports can be customizable to a variety of users, i.e. executive reports, financial reports, scheduling reports, kitting reports, required hardware reports, etc.
5. The production line (and VP) is intended and designed to be mass customizable. In other words, cells can be rapidly modified/reconfigured in order to allow for revisions/upgrades/modifications, etc.
6. The virtual prototype is tailorable to any missile/weapons configuration one can imagine. The prototype is a tool used to evaluate systems with a drawing package with discrete components/assemblies identified.

Acknowledgments

The authors would like to thank the team who worked this VP effort, the MMS community at NAWC, China Lake, and management support/encouragement for pursuing this paper.

Naval Air Warfare Center Weapons Division

Virtual Prototype Manufacturing of a Miniature Munition System

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Code 475000D

November 17, 2010

China Lake, California

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What is a Virtual Prototype (VP)?

- Likely a wide array of answers
- No right or wrong answer
- A computer generated model/simulation in which one can derive some form of useful information
  - Model/Simulation pertains to manufacturing of a miniature munition system (MMS)

Assumptions and Constraints

- Is it Reality or is it Memorex?
- Isotropic/Homogenous Materials?
- Perfect World/ "0 Defects"
- However, you have to start somewhere

Assumptions and Constraints (cont'd)

- Sufficient manpower exists for manufacturing
  - No manpower shortage, absenteeism, or lack of skilled/unskilled laborers
- Work is completed within a single 8 hr shift
  - Can be easily modified to adapt to multiple shifts
- If a given worker is transitioning from one task to another, no added cost or time are incurred
- 100% efficiency for each worker is assumed initially
  - Can be varied based upon measured/actual values

Assumptions and Constraints (cont'd)

- Both Linear/Parallel processing is allowed
  - Appropriate rules must be established with respect to their contribution to the VP
- External manufacturer's (suppliers) information is input and a contributor to the VP/timeline of events
- All components are assumed to be compliant, tested, verified
  - No contributor to scrap, rejected hardware/assemblies, or waste stream
  - Future versions will have provisions for the contribution of scrap, non-compliant hardware, etc.

Architecture

- All Up Round (AUR) Missile Assembly (Top Level)
  - Guidance & Control (G&C) Assembly
    - Seeker Assembly
    - Servo/Control Assembly
    - Guidance Electronics Assembly(s)
  - Ordnance Section
    - Warhead Assembly
    - Fuze/ESAD Assembly
  - Propulsion Assembly
    - Rocket Motor Assembly
    - Igniter Assembly
  - Software

Manufacturing Cell Contributors

- Purchased items - essentially commercial off the shelf (COTS)
- Manufactured items - items which are organically manufactured by the prime
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- Kitted items - items that are coalesced into an aggregated form in order to feed the specific subassembly
- Consumable/Perishable Items
- Tooling - both permanent and perishable tooling required to facilitate/manufacture/assemble individual components or assemblies
- Touch Labor Cells
- Robotic Assembly Cells

VP Software

- Extend
  - Process Modeling Tool
  - Time discrete event modeling or continuous modeling for simulations and/or analysis
  - Allows for proper architecture (user defined)
  - Extremely powerful tool
  - Easy to modify
  - Capable of multiple runs/analyses based upon predictions/futuring/assumptions

VP Software (cont'd)

- ARENA
- PMCorp Software
  - WITNESS
  - SIMUL8
  - AUTOMOD
- Siemens Software
  - TECNOMATIX
  - TEAM CENTER VISUALIZATION
- Navy IT Requirements Hinder S/W Packages

Results

- VP created
- Data input
- Simulations/scenarios analyzed/evaluated for a MMS
- VP tested with a variety of basic assumptions and constraints
- Cycle times, costs, subassembly/assembly times were established in order to derive tangible data regarding the MMS evaluated
- Validate existing data sets and current beliefs of the MMS for manufacturing
- Data can be use for
  - Manufacture a short run of DT/OT rounds
  - Fleet readiness/rapid reaction quantity for employment in theater

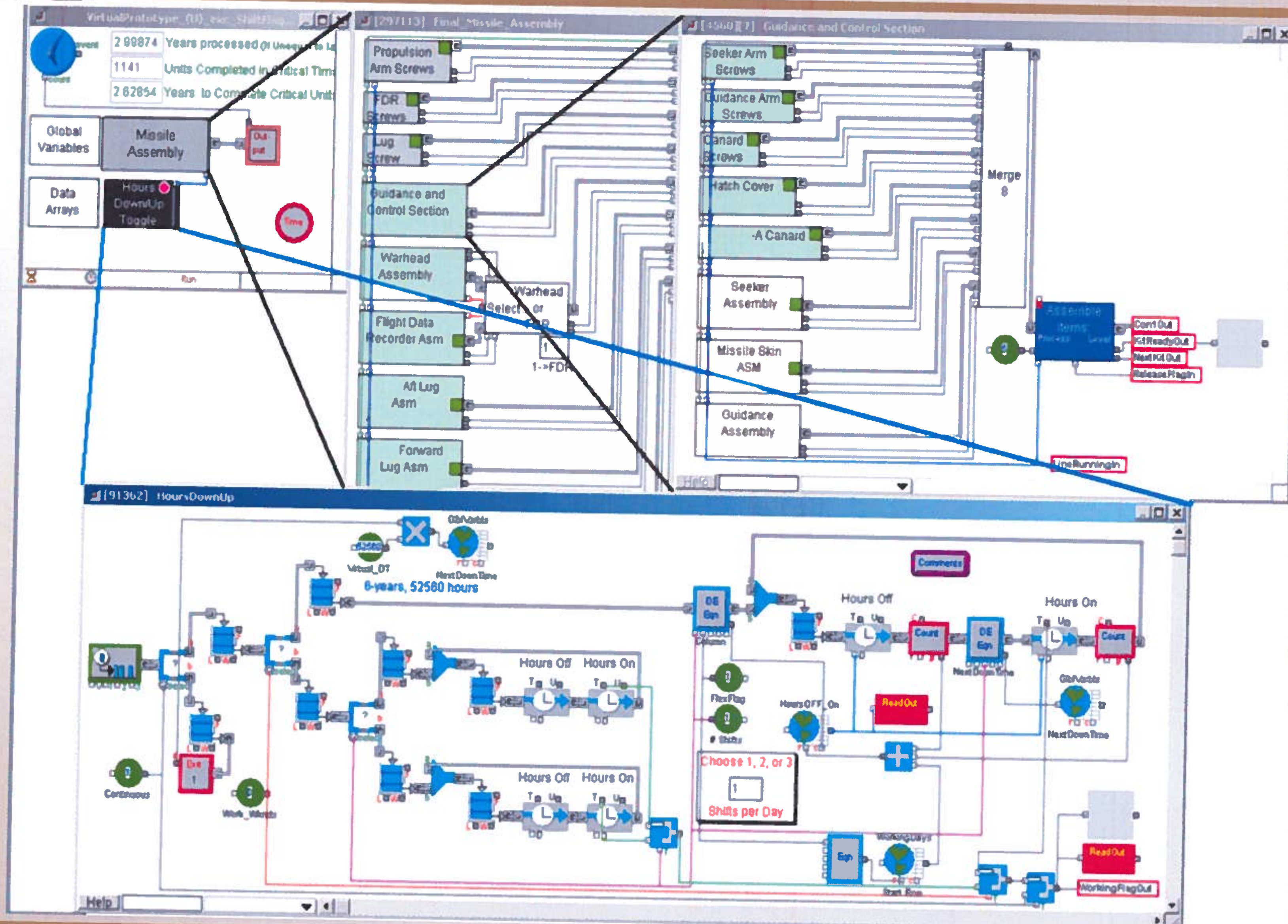
Results (cont'd)

- Tool was helpful in identifying potential bottlenecks, supply chain issues, and both cost and schedule concerns/beliefs
- Established architecture and drawing package validation
  - Mechanical
  - Electronic
  - Assemblies
- Established processes/procedures for building missiles
- Established following analyses for:
  - Cost
  - Cycle Time (Individual & Total)
  - MMS Throughput
  - Supply Chain Issues
  - Surge Capabilities

Results (cont'd)

- Identification of Critical Paths and/or Bottlenecks in the production line
- Identification of Limitations and Constraints with respect to the current MMS design
- Identification of Limitations and Constraints with respect to Supply Chain Issues
  - Raw Material Availability
  - COTS availability & production capacity of subcontractors
  - Saturation Levels
  - Proprietary components/assemblies contained within the MMS
  - High Cost/High Lead Time materials or components

Results (cont'd)



Future Work

- Further development of the virtual prototype will occur depending upon funding and current/future projects which might find utility with the virtual prototype
- VP can be used for production environments and for determining production volumes, cost, schedules, etc.
- Add a GUI type interface can be designed in order to allow non-technical users to input data or produce rudimentary simulations for quick analysis.
- Module allowing for plant footprints and even a "virtual walk-thru" of the plant to add visual and enhance the prototypes capabilities.
- A proper design for manufacturability (DFM) needs to be conducted on the pertinent system prior to initiating a production cell

Future Work (cont'd)

- The VP allows for one to evaluate current methodologies and identify long lead items, long cycle times for assembly, etc. which give "low-hanging fruit" in order for a proper DFM to be initiated.
- Tying the VP to an inventory management system would be considered to be a likely follow-on.
- Questions such as could likely be answered:
  - When will I run out of parts?
  - Will I run out of parts?
  - What are long lead items?
  - Which items are cost drivers?

Future Work (cont'd)

- Quality assurance provisions
  - Defect or rejected hardware
  - Scrap rate
- Initially the model assumes 100% acceptance but reality dictates a given scrap/defect rate for any process of manufacturing or assembly
- Rework and/or repair can be incorporated
- Envisioned that the VP will be able to predict or determine feasibility of rework/repair or to truly scrap and remove the hardware in terms of cost/schedule decision points
- Vendor performance can be evaluated/predicted
  - On-time delivery
  - Approximate scrap rate
  - Rate of rejected hardware/assemblies

Conclusions

1. The VP does not always rule. Keep in mind, the VP can be wrong and conclusions drawn from the VP should be carefully examined and validated with respect to reality if at all possible.
2. Application/Interpretation of the model must be done carefully as to not misconstrue actual production rates/numbers

Conclusions (cont'd)

3. The VP is only as good as the assumptions and constraints established. Further, the old adage "garbage in – garbage out" applies. The use of robust data will yield a proper output.
4. Reports can be customizable to a variety of users, i.e. executive reports, financial reports, scheduling reports, kitting reports, required hardware reports, etc.

Conclusions (cont'd)

5. The production line (and VP) is intended and designed to be mass customizable. In other words, cells can be rapidly modified/reconfigured in order to allow for revisions/upgrades/modifications, etc.
6. The virtual prototype is tailorable to any missile/weapons configuration one can imagine. The prototype is a tool used to evaluate systems with a drawing package with discrete components/assemblies identified.