

FINAL PERFORMANCE REPORT

Contract/Grant Title: USING ADVANCED TABU SEARCH APPROACHES TO PERFORM ENHANCED AIR MOBILITY COMMAND OPERATIONAL AIRLIFT ANALYSES, PHASE III

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Executive Summary

The descriptions below are intended to complement and expand upon the abstract contained in the cover page (Report Documentation Page, Standard Perform 298) for this final report.

Each of the doctoral dissertations and final Masters degree documents, either reports are theses, completed during the report period, will be briefly summarized, where appropriate, giving the most significant advancements and conclusions contained in each document. The descriptions will be given in the order of presentation in the references given at the end of this report. First, we will describe the 4 dissertations completed during report period. These dissertations are available through The University of Texas at Austin.

The work by Roesener [1] and Roesener et al. [27] documents an advanced tabu search (TS) approach to both the static and dynamic airlift loading problem. It represents an extension of Harwig's seminal work [5,19] on the two-dimensional orthogonal bin packing problem. However, in Roesener's research, additional constraints associated with military aircraft such as weight and balance had to be considered. Roesener's methodology was shown to be *significantly* superior to standard practices employed at the time of its development.

The research of Yang [2] and Yang et al. [29] was the first documented research in applying TS to the correction of disruption management problems in the civilian airline industry. This highly innovative research employed both pure TS and a hybrid mathematical programming-TS approach to the aircraft grounding problem and to the reduced airport capacity problem to achieve superior results in both cases. While Kinney [8] and Kinney et al. [20] also used a hybrid methodology, the problems approached by Yang were considerably more restrictive in the context of the associated constraints.

The research documented in Ciarleglio [3] and Ciarleglio et al. [22, 23] constitute a major breakthrough and departure from previous work in TS. This research resulted in a fundamental reusable framework, the modular adaptive self learning TS (MASTS) for the application of advanced TS techniques. Surpassing the purview of just being a

powerful generalized search framework, MASTS provides its clients with a flexible and inclusive architecture to build applications with user friendly graphical user interfaces (GUIs) that embrace such things as user transparent multithreaded capability, persistence, and solution archiving. Not only does MASTS embody good design practices, it also includes some highly desirable innovations such as Rule Based Objectives (RBOs) and Dynamic Neighborhood Selection (DNS) that aid greatly to its strength. Initial applications of MASTS to exceptionally challenging problems such as Ground Water Management and Species Conservation [22,23] have produced unprecedented successes and have established MASTS at the forefront of direct search methodologies.

MASTS has been incorporated into Sandia National Laboratories CADRe package, is being used by several water conservation districts and has been used to set forth a new standard for the construction of species conservation networks. The development of MASTS and its acceptance and use by Sandia National Laboratories in its CADRe package and by governmental water management agencies demonstrate that MASTS is a *major new invention*. MASTS application, with its cutting edge *rule based objective function* technology, to the species conservation network problem has led to *numerous discoveries* that will directly lead to the next generation of tools for the effective and efficient solution of problems associated with classical set covering and knapsack problems that must incorporate additional complex real world constraints. Such complex set covering and knapsack problems abound in real world practice. Many real world problems cannot be modeled effectively (if at all) by classical mathematical programming approaches but are easily and effectively modeled within the MASTS framework.

The research documented in Michalopoulos [4] is apparently the first attempt to apply TS to the stochastic network interdiction problem. Under the supervision of Professor's David Morton and J. Wesley Barnes, Michalopoulos was able to develop a pure mathematical programming approach, a pure TS approach and a hybrid mathematical programming-TS approach to two major types of stochastic network interdiction problems. The hybrid methodology proved to be significantly superior both in the quality of the solutions obtained and the effort required to obtain of solutions. Michalopoulos achieved this greatly improved approach by using important knowledge and attributes gained from the mathematical programming perception of the problem to very effectively guide the search decisions employed in the TS portion of the hybrid approach.

We now turn our attention to the Masters degree documents [10-15] completed during this report's period. Each of these reports are available from the Department of Mechanical Engineering at The University of Texas at Austin.

Barriero's MS Report [10] investigated previous work in the hybridization of constraint programming, classical mathematical optimization, and direct search approaches including TS. Barriero also developed a prototype hybrid of constraint programming and TS for a classical sequencing problem. Roger's MS Report [11] documented the current practices used by the US military for casualty and medical evacuation.

Whilden's MS Report [12] investigated the use of statistical design of experiments (DOE) within the US Army testing community. He found that there was very little use of DOE by that community even when its use would have been superior to the techniques actually employed. The report contained a set of recommendations for the future more extensive use of DOE by the Army testing community and also suggested feasible approaches to obtain the appropriate training for the associated personnel. Harvey's MS Report [13] documented the current practices used by the U.S. Army to move personnel and materiel from locations within the continental United States to aerial and sea ports of embarkation. This work was preparatory to the future building of a TS-based planning tool to optimize that logistics problem.

Ramirez' MS Report [14] documented the current practices employed by the United States military to load pallets for subsequent transport between two or more locations both by air and ground vehicles. This work was preparatory to the building of future models to improve the current methodologies.

Dashora's MS Thesis [15] presented a well documented guide that will greatly assist future MASTS clients in making *full* use of the powerful tools and methodologies embedded within MASTS. The thesis illustrated how to utilize the MASTS framework [3] to solve combinatorial optimization problems involving not only binary solution representations, but also permutations and partitions. Given such an illustration and the documentation for MASTS provided in the thesis, future clients should be able to apply MASTS to successfully attack general combinatorial optimization problems. The thesis also provided a descriptive manual of how a user would start building professional level applications using MASTS and clearly discusses the *Java classes* that *must* be custom built by a user and the pre-built classes that exist to assist various basic strategies.

The Ph.D. dissertations and the papers contained in the references to this final report which have not been explicitly addressed in this final report were addressed in AFOSR progress reports associated with periods prior to the timeframe associated with this final report. The dissertations within this group are available from The University of Texas at Austin. The papers within this group are available from the journals cited in the references. Individuals associated with the research reviewed in this report are named in the references section at the end of this report. Additional information about these individuals or any other component of the research associated with this report may be obtained by contacting Principal Investigator of this project.

References

Ph.D. Supervisions Completed during Final Report Period

1. August G. Roesener, 2006, *An Advanced Tabu Search Approach To The Airlift Loading Problem*
2. Mei Yang, 2007, *Disruption Management for the Airline Industry Using Tabu Search*
3. Michael Ian Ciarleglio, 2008, *Modular Abstract Self-Learning Tabu Search (Masts) Metaheuristic Search Theory And Practice*
4. Dennis P. Michalopoulos, 2008, *Modeling and Solving Stochastic Prioritized Network Interdiction Problems*

Ph.D. Supervisions Completed before Final Report Period (but referenced in published papers during report period)

5. John Harwig, 2003, *An Adaptive Tabu Search Approach to Cutting and Packing Problems*
6. Boryanna S. Dimova, 2004, *Characterizing Neighborhoods Favorable to Local Search Techniques*
7. Garrett R. Lambert, 2004, *A Tabu Search Approach to The Strategic Airlift Problem*
8. Gary W. Kinney Jr., 2005, *A Group Theoretic Approach to Metaheuristic Local Search For Partitioning Problems*
9. Kaye McKinzie, 2005, *A Tabu Search approach to Strategic Mobility Mode Selection*

M.S. Supervisions Completed during Final Report Period

10. Javier Barreiro, 2006, "Integrating Constraint Programming with Mathematical Optimization and Local Search techniques"
11. Irving S. Rogers, 2007, "Casualty And Medical Evacuation In The United States Army"
12. John N. Whilden Jr., 2007, "Design of Experiments Within Army Testing"
13. Michael J. Harvey, 2007, "The Strategic Mobility Problem- Fort To Port Segment"
14. Jose A. Ramirez, 2008, "A Study of Current & Future Methodologies Of The Pallet Loading Problem in U.S. Military Logistics "
15. Yogesh Dashora, 2008, "A User's Insight to MASTS (Modular Adaptive Self-Learning Tabu Search)"

Refereed papers published during Final Report Period

16. Porter, J., M. Larson, J.W. Barnes, and J. Howell, "Metaheuristic Optimization of A Discrete Array of Radiant Heaters," *Journal Of Heat Transfer*, Vol. 128, 2006, pp. 1031-1040.
17. McKinzie K. and J. W. Barnes, "A Tabu Search Approach to the Strategic Mobility Mode Selection Problem," *Air Force Journal Of Logistics*, Vol. 30, No. 3, 2006, pp. 51-61.
18. Dimova, B., J. W. Barnes, and E. Popova, "The Characteristic Neighborhood Equation for an AR(2) Landscape," *Applied Mathematics Letters*, Vol. 19, No. 6, 2006, pp. 260-266.
19. Harwig J., J.W. Barnes, and J. Moore, "An Adaptive Tabu Search Approach for 2-Dimensional Orthogonal Packing Problems," *Military Operations Research*, Vol. 11, No. 2, 2006, pp. 5-26.
20. Kinney, G., J. W. Barnes, and B. Colletti, "A Reactive Tabu Search Algorithm with Variable Clustering for the Unicost Set Covering Problem," *The International Journal Of Operational Research*, Vol. 2, No. 2, 2007, pp. 156-172.
21. Lambert, G., J.W. Barnes, and D. Van Veldhuizen, , "A Tabu Search Approach to the Strategic Airlift Problem," *Military Operations Research* , Vol. 12, 2007, pp. 59-79.
22. Ciarleglio, M., J. W. Barnes, and S. Sarkar, "ConsNet - A Tabu Search Approach to the Spatially Coherent Conservation Area Network Design Problem," *Journal Of Heuristics*, 2008, pp. 1-15, (accepted and available online (DOI 10.1007/s10732-008-9098-7), hardcopy forthcoming).
23. Ciarleglio, M., J. W. Barnes, and S. Sarkar, "ConsNet: New Software for the Selection of Conservation Area Networks with Spatial and Multi-Criteria Analysis," *Ecography*, 2008, pp. 1-7, (accepted to appear).
24. Dimova, B., J.W. Barnes, E. Popova and B. Colletti, "Some Additional Properties of Elementary Landscapes," *Applied Mathematics Letters* , 2008, pp. 1-4, (Online Only).

25. Cain, W, J.W. Barnes, M. Ciarleglio, S. Pierce, "CADRE: A negotiation support system for sustainable water management," *Proceedings Of Water Down Under 2008 Incorporating The 31st Hydrology And Water Resources Symposium And The 4th International Conference On Water Resources And Environment Research (ICWRER)* , Adelaide, South Australia 14-17 April 2008, 2007, 12 Pages,, Adelaide, South Australia 14-17 April 2008, 2008, pp 1-12.
26. Moore, J., J. Wesley Barnes, and R. Hill, "Modeling the End-to-End Military Transportation Problem," *Handbook Of Military Industrial Engineering*, accepted, to appear 2009, pp 1-86, published by Taylor and Francis/CRC Press.
27. Roesener, A., J. W. Barnes, J. Moore, D. Van Veldhuizen, "An Advanced Tabu Search Approach To The Static Airlift Loading Problem," *Military Operations Research*, 2007, (in second review).
28. Burks, R., J. Moore, and J.W. Barnes, "Solving Theater Distribution Problems with Tabu Search," *Military Operations Research*, 2008, pp. 1-39, (in second review).
29. Yang, M., J.W. Barnes, and J. Pachon , "Using Tabu Search to Solve the Reduced Airport Capacity Problem," *Transportation Science*, 2008, pp. 1-27, (in review).[3]

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14. ABSTRACT This two year and 10 month period (immediately preceded by contiguous six years of AFOSR funding) saw the graduation of 4 PhD [1-4] (bracketed numbers refer to the references given at the end of this report) and 6 MS students [10-15]. Eleven refereed papers [16-26] were published or accepted, 2 are in second review [27,28] and 1 is in its first review [29]. The Grant PI, Dr. J. Wesley Barnes was named to both The University of Texas at Austin Mechanical Engineering Hall of Fame and Mechanical Engineering Academy of Distinguished Alumni. In addition to the continuing work on the end-to-end United States Military Logistics problem [1,5,9,11,12,13,14,17,19,21,26,27,28] and on the in-depth theoretical study of general landscape theory associated with direct search methods (in particular, tabu search (TS)) [6,18,24], inroads into three new major areas of research, extending previous domains, were achieved: (1) initial highly successful work in the area of disruption management [2,29], (2) the development and capability of a generalized framework, Modular Adaptive Self-Learning Tabu Search (MASTS) was proven in 3 distinct application arenas [4,15,22,23,25] and (3) promising collaborative work with Dr. David Morton in hybrid methods of stochastic optimization using classical and advanced tabu search methods [4].					
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