The NASA
Mission Dependency Index (MDI)
User Guide

Identifying the Relative Importance of Facilities

Version 2.0

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1.0 Definitions

Interruptability. Tolerance for interruption of service or access. It measures how long the "functions" supported by a specific *Facility Component* or *Functional Element* can be interrupted without adverse impact to the mission.

Relocateability. The difficulty or cost to relocate the "functions" performed or supported by a *Facility Component or Functional Element* to another *Facility Component or Functional Element* without adverse impact to the mission(s) being performed.

Replaceability. The difficulty or cost to replace or replicated products or services from an alternate provider outside the *Center* (other *Functional Areas* or by using other *Centers* or off-center contractors) without impacting *Mission Readiness*.

Repairability. The ability/cost to repair the a *Facility*, *Facility Component*, *System*, or *Equipment* in place without adverse impact to the *Mission(s)* being performed.

Intradependency. All *Facility Components* or portions thereof which are under the direct control of a *Functional Area.*

Interdependency. The direct reliance on other organizations that provide products or services .

2.0 Purpose

Facilities need to be sustained, restored, modernized and disposed so as to meet mission requirements. These processes have substantial costs and require prioritization. MDI identifies the relative importance of facilities in terms of mission requirements from the perspective of managers who use (occupy) the facilities to perform their functions, rather than from the perspective of the real property and facilities engineering community. MDI is not a goal directed metric because there is no ideal score to achieve. It is a metric which is useful in combination with other facility management metrics to make both strategic and tactical decisions. For example, MDI can be used to support decisions related to:

- Decrease non-essential facilities (Divestiture)
- Identify critical nodes for redundancy upgrades
- Prioritize construction of facility (CoF) submissions
- Optimize facilities maintenance and repair strategies
- Improve space assignments by more appropriate clustering or dispersal of critical facilities
- Improve master planning through clear understanding of program/facility requirements
- Improve security/emergency plans through comprehensive facility assessment in terms of program requirements
- Improve energy conservation through aligning critical spaces and HVAC zones

3.0 Background of Mission Dependency Index Development

The MDI was originally developed by the Naval Facilities Engineering Service Center (NFESC) in Port Hueneme, California [Antelman A. and Miller C.] in partnership with the United States Coast Guard Office of Civil Engineering [Dempsey J. and Antelman A] as a risk-based metric that links facilities to a pre-established, self-imposed objective or goal, referred to as mission. Subsequently, the Federal Real Property Council (FRPC) established by Executive Order 13327, Federal Real Property Asset Management, decided that four key measures should be associated with all Federal real property assets: Condition Assessment, Utilization, Cost, and Mission Dependency [Bernstein P. L].

MDI is based on principals of risk management and utility theory [Samson D]. MDI uses Operational Risk Management (ORM) techniques of probability and severity and applies them to facilities in terms of *Interruptability*, *Relocatability, Replaceability, and Repairability* [OPNAVINSTR 3500.39B]. MDI also takes into account mission "Intra" dependencies (those that reside within an organizational unit) and mission "Inter" dependencies (those that reside between organizational units). It does this through a simple structured interview and question process that captures the "experience, judgment, intuition and situational awareness of leaders having authority over operational and facility decisions."[OPNAVINSTR 3500.39B] The product is a quantitative score normalized over a scale from 0 to 100, with higher scores representing higher mission dependencies or mission critical facilities.

MDI is similar to Failure Modes and Effects Analysis (FMEA) and Reliability Centered Maintenance (RCM). All three metrics use time as their primary measure. MDI parallels FMEA and RCM in answering one of three maintenance related questions:

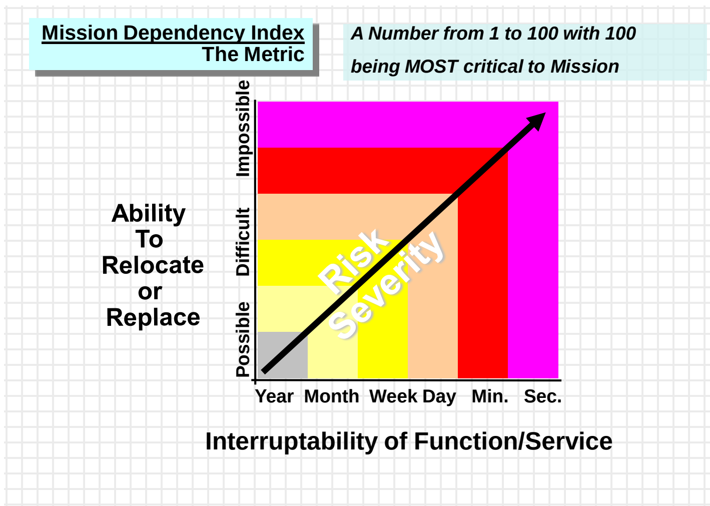
- FMEA: When will it fail?
- MDI: When does it need to be fixed?
- RCM: How often should it be maintained?

These three metrics provide a view into the same decision space from different perspectives.

NASA decided to employ the MDI in part as a response to the FRPC requirement, but also due to the growing awareness that it needed to improve the alignment between its strategic plan and its facilities. Subsequently, others have favorably reviewed the MDI method. According to a Federal Facilities Council report, the MDI supports and is consistent with Federal Facility Asset Management principles [Cable J. H. and Davis J. S.]. It has been recognized as a "Best Practice" by the General Services Administration [Lomax M]. It has also been reported in publications of the National Academy of Sciences' National Research Council, the Association of Physical Plant Administrators, the Federal Real Property Council and others [Antelman A. and Clayton J], [Singh H. and Kinnaman M], [Brodt]. MDI has now been adopted by the USACE and the USAF, and other agencies are considering its adoption, because it provides a logically consistent, risk-based approach to assessing the importance of facilities among multi-mission and multi-location organizations.

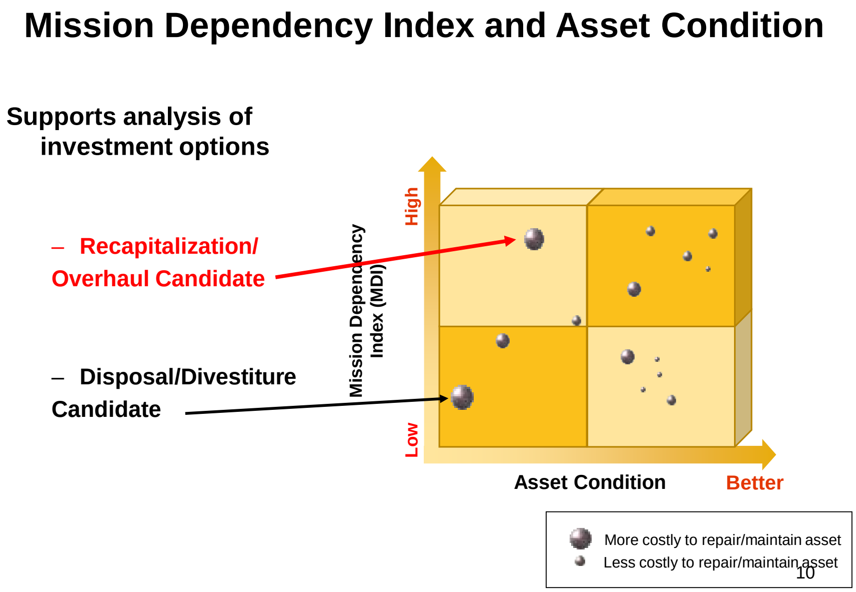
The MDI approach involves asking the user of an asset to honestly assess the capability of the organization to continue to perform its mission when the asset is not available. Many functions can be interrupted for short periods without impact because other activities which require a different set of facility resources can be substituted. Very simply, sometimes a work schedule or work location can be changed without impacting upon the overall mission. When the Navy and Coast Guard originally applied the MDI, they used four time duration levels of interruption of services and three levels of difficulty in relocating or replacing the activity. Figure 1 graphically depicts this concept.

Figure 1 Navy Mission Dependency Index Risk/Severity Graphic



Booz Allen Hamilton employed MDI in a recapitalization study for NASA using key assets related to the Shuttle Program with data from the NASA Deferred Maintenance Condition Assessment Model as indicated in Figure 2. This study also loosely explored the relationship between facilities and the associated workforce using mission dependency as a linking factor.

Figure 2



The NASA MDI methodology was jointly developed by NASA and the Naval Facilities Engineering Support Center through adapting the U.S Navy and U.S. Coast Guard approach. NASA incorporate a stronger maintenance perspective and the extended the time horizon to several years to accommodate the uncertainty regarding future use of expensive research facilities. The definitions for the factors of Replaceability, Relocateability and Repairability were modified to add the concept of cost. *Relocatability* and *Replaceability*, measured by difficulty, were the most accurate and relevant measures for operational facilities associated with launching and controlling spacecraft. *Repairability* was added to better represent maintenance, one-of-a-kind infrastructure, and equipment which has no equivalent elsewhere. Although many functions can be relocated temporarily should the primary location become unusable, it may be nearly impossible to relocate, repair or replace a function performed with a special purpose facility. It may be necessary to keep such an asset in relatively good condition even if it is not needed in the shorter planning horizon of typical operational programs.

These considerations are expressed in the form of two questions and associated definitions for the alternative responses:

> *Question 1*: How much time can a Facility/Lab/Shop/System/Equipment be unavailable for scheduled maintenance, relocation or repair?
>
> *Question 2*: If the Facility/Lab/Shop/System/Equipment was unavailable, how costly, unique, or difficult is it to use another Center/Contractor/Activity/ Agency/ Facility/Lab/Shop/System/Equipment?

The questions and responses are consistent with NASA's policy and procedural approach to risk management.

The first interviews were performed at Wallops Flight Facility by Navy personnel and contractors in 2004. Subsequently most facilities and all NASA Centers were reviewed by 2006. The MDI model was incorporated into the NASA Real Property Information System in 2007. The data was updated in FY2009 by Center staff with assistance from HQ and Navy staff in some cases.

The MDI application and data was converted to the IEMP/SAP/ Flexible Real Estate module in 2010. Several simplifications were made during this conversion, reflecting the collective experience of HQ and Center staff in an effort to improve the balance between the benefit of obtaining useful assessments from NASA managers versus the cost and difficulty of maintaining the database. These changes are explained below. The intent is to maintain the database with the same frequency and accuracy as the facility utilization portion of the Flexible Real Estate module. According to NPR 8800.15B, Real Estate Management Program, organization moves should be documented as they occur, and the database should be completely reviewed every three years.

4. Model Description and Procedures

Asset Definition. MDI permits, but does not require, decomposing complex infrastructure into multiple levels. In the initial NASA survey, each Center determined the level of decomposition of its facilities: some used the real property asset while others subdivided into rooms or systems as indicated in the following examples:

- Facility – Building
- Facility Component – Room/Space
- System – Service
- Equipment – Fixed/Large/Unique/Costly
- Linear Structure – Road/Rail/Pipeline/Fence/Pavement/Bridge
- Network Facilities – Utility/Network

With the conversion to the Flexible Real Estate module, it was decided to restrict data collection to the real property asset. Centers desiring to implement MDI at more detailed levels should do so within Center facility management databases.

"Intra" and "Inter" Dependency: "Intra" (within) and "Inter" (between) dependency measure infrastructure and relationships. Both measures use *Interruptability*, *Relocatability*, *Replaceability* and *Repairability*. *Intradependency* directly measures Center's infrastructure and is answered by the managers. Interdependency measures relationships between organizations and the other organizations which use their services. Originally, each manager answered MDI questions about the organizations upon which it depends for services. These responses were then reflected back so that each organization receives its interdependency assessment based upon how other organizations rate it. With the conversion Flexible Real Estate module, it was also decided to simplify the interdependency assessment and use a set of constant values. Navy staff reanalyzed the original data collected in 2004-2006 in the context of NASA's decision to use the Work Breakdown Structure at the Directorate Level for organization structure, and generated a set of interdependency values to be used as constant values across all Centers. These values are shown in Table 1 below. A difficulty with this assessment choice is that sometimes a subcomponent drives the score, such as Center Operations gets the maximum score of 16 when is only the Utilities portion merits the high score. It would be reasonable to periodically reassess these interdependency scores.

Organization Structure. NASA HQ originally permitted each Center to establish its own set of organizations. In an effort to get assessments for facilities from the most knowledgable users, some Centers interviewed more than 100 managers. Experience with trying to assess the interdependencies and manage a database with this number of entities led to the conclusion that the interview approach was more suitable to handling from 30 to 50 entities. This level of detail was deemed to provide a reasonable balance between stability (structure will not change due to lower level reorganizations) and accuracy (managers are sufficiently aware of the requirements of the actual users of the facilities). At the time of the conversion of the NASA Real Property Information System to the SAP/Real Property Module, it was decided by the people working on Facility Utilization to implement organization tracking via the NASA Work Breakdown Structure at the Directorate Level. While this is not a perfect choice from the MDI modeling perspective because the Navy's analysis disclosed that some subcomponents of Directorates generate high interdependency scores while other subcomponents do not, the Directorate choice is reasonable from the perspective of managing the overall RPM database.

Table 1 Interdependency Scores by Directorate

Code	Directorate Title	Interdependency Score
1001	Exploration System Mission Directorate	6
1002	Strategic Integration & Management Office	3
1003	Constellation Systems Division	3
1004	Space Operations Mission Directorate	7
1005	Launch Services	5
1006	International Space Station	3
1007	Space Shuttle Program	4
1008	Science Mission Directorate	1
1009	Aeronautics Mission Directorate	3
1010	Office of Safety and Mission Assurance	6
1011	Office of the Chief Financial Officer	5
1012	Office of the Chief Information Officer (IT)	9
1013	Engineering Directorate	10
1014	Office of the General Council	3
1015	Office of Chief of Strategic Communications	3
1016	Office of Public Affairs	2
1017	Office of External Relations	2
1018	Office of the Inspector General	3
1019	Office of Center Operations	16
1020	Office of the Director	7
1021	Office of Human Capital	5
1022	Office of Diversity and Equal Opportunity	1
1023	Office of Procurement	6
1024	Programs & Projects Office	5
1025	Plum Brook Management Office	
1026	Research & Technology Directorate	10
1027	Test Directorate	6
1028	Systems Management Office	1
1029	Research Services Directorate	8
1030	Business Operations Office	4
1031	Advanced Planning & Partnerships Directorate	3
1032	Extravehicular Activity Office	1
1033	Office of Knowledge & Quality Management System	9
1034	Commercial Crew & Cargo Program Office	0
1035	Space Life Sciences Directorate	3
1036	Solar System Exploration	8
1037	Mars Exploration	5
1038	Astronomy and Physics	9
1039	Earth Science and Technology	2
1040	Interplanetary Network	7
1041	Resident Office	1
1042	Inactive (Mothball/Standby/Abandoned)	
1043	Other	4

Interruptability and Time: MDI uses time as its primary measure for *Interruptability*. Time scales ranging from immediate (24/7), hours, days, weeks, up to a month reflect operational facilities. NASA extended time scales up to 1, 5, and 10 years to match the planning horizon for space exploration. NASA also includes "vacant" to support divestiture.

Table 2 MDI Interuptability Timeframes

Interruptability Timeframes	
Immediate	Must be Maintained Continiously (24/7)
Urgent	Minutes up to 1 Hour
Brief	Hours up to 1 Day
Short	Days up to 1 Week
Prolonged	Weeks up to 1 Month
Extended	Months up to 1 Year – 1 Week to Operational
Future	Years up to 5 Years – 1 Month to Operational
Mothball	5 – 10 Years – 1 Year to Operational
Vacant	Available for Others – To Be Demolished

Relocatability, Replaceability, Repairabilty and Cost: NASA uses cost as its primary measure for *Relocatability, Replaceability, and Repairabilty*. These three measures identify alternative location or source. *Relocatability* is with another group or facility inside a *Center*. *Replacability* is with another *Center*, activity, or contractor outside a *Center*. *Repairability* is "fix it in-place" when no other alternative is possible.

Table 3 MDI Relocatability/Replaceability/Repairability Options

Relocatability, Replacability and Repairability	
Impossible	One of a kind capability in NASA/N.A.; Relocation/repair requires $1,000k's; Major program/schedule interruption; Integral to Center.
Extremely Difficult	Very few alternatives with capability exist in NASA/N.A.; Somewhat unique capabilities Relocation/repair requires $100k's; Significant program/schedule delays; No spares; Very large/heavy components.
Difficult	Alternate capability exists; Relocation/repair requires $10k's; No significant impact on schedule/program;
Possible	Alternate capability is readily available; Relocate/repair cost $k's; No program/schedule impact.

Data Collection

The NASA MDI application is located at: https://mdi.nasa.gov/ Users must have the appropriate NASA User Name and Password to view the data, and the MDI_UPDATE role in order to add or change data.

Training in use of the MDI application is available at: https://bready.nasa.gov/portal/server.pt/community/initiatives_community/real_property_management and also at: https://mdi.staging.nasa.gov/

Default Values: Based upon early interviews, office and administrative spaces have nominal default values of up to one-week Interruptability (Q1:Short) and easy Relocatability (Q2:Possible). (Individuals could be on vacation or trips for a week, and could easily relocate to another office and access e-mail and files, without mission impact.)

Scenarios: Assuming facilities are being used isolates importance (MDI) from utilization. Many testing facilities are less frequently used and can be down for maintenance for extended periods. MDI scores for these extended periods would then be artificially low, limiting useful comparison. The general scenario used for the questions is a scheduled outage in the midst of "preparing for, or performing the function or mission of that Facility."

The advantage of obtaining the MDI assessments from program managers rather than from facility management personnel is that the user is best able to answer the questions accurately. Some people question whether facility users will honestly answer the questions. The keys to obtaining a good assessment seem to be (a) questioning responses which indicate a very high risk exists, (b) asking if an emergency plan to maintain continuity of operations needs to be established, and (c) helping the facility user consider possible emergency options. Very simply, answers which suggest a high risk need some confirming explanation before making that "high risk" designation. When the assessments are complete and accurate, the Center Director should have confidence in the results.

Converting Interview Responses to Scores and Reports

An MDI score should be used as a basis for sorting facilities into those which may need some additional consideration, and those which most likely do not. The correct MDI for a facility is the result of the most accurate answers to the MDI questions. A high score is not "Good" and a low score is not "Bad". A high score does indicate that the facility is important and/or it is very difficult to find a substitute facility. A high score implies that the facility should be kept in good condition, needs priority response to maintenance service calls, and a COOP may be appropriate. In contrast, a low score might suggest an opportunity for a new use or closure. The determination should be derived from analyses subsequent to the interview and scoring processes, not from MDI scores alone.

While interruption and relocation have individual implications for acceptable facility condition and maintenance service response time, the MDI algorithm combines the factors into a linear scale. The scale is then mapped into both a five level adjective rating and a three level adjective rating. Depending upon the purpose and the level of confidence in data set, each of these three MDI metrics should be useful. To date, NASA has used the three level rating to report to the General Services Administration for the Federal Real Property Council requirement and as a loosely defined factor to consider in establishing priorities for proposed facility construction projects. Employing the five level ratings for internal NASA analyses is a reasonable step in increasing use of the MDI.

It is noted that while the Mission Dependency Index concept is increasingly accepted, debates regarding the relative weighting of components of the index and even the questions used in the assessment continue to be debated among proponents of the metric.

Table 4

Mission Dependency Index (MDI) Web Application

MISSION INTRA-DEPENDENCY SCORE										
MD_W		Q1: Interruptability								
		Immediate (24/7)	Urgent (min/hr)	Brief (hrs/day)	Short (days/week)	Prolonged (weeks/month)	Extended (months/year)	Future (1 - 5 Years)	Mothball	Vacant
Q2: Relocatability Replaceability Repairability	Impossible ($M's)	84	81	75	66	54	42	30	2.5	0
	Extremely Difficult ($100K's)	78	72	63	51	39	27	18	2.0	0
	Difficult ($10K's)	69	60	48	36	24	15	9	1.5	0
	Possible ($K's)	57	45	33	21	12	6	3	1.0	0
MD_W = Mission Dependency Within a Functional Element										

MDI = (MDw) + (MDb)

"Intra" dependency Score: MDw = 0 → 84, (from Table above)
"Inter" dependency Score: MDb = 0 → 16, (constant for each Standard Organization)

Statistical analysis was performed on NASA MDI data to determine optimum values for category thresholds as shown in Table 4. The objective was to reduce arbitrary partitioning of categories. NASA reports MDI to the Federal Real Property Profile at the Real Property Asset level. The MDI of an Asset is the highest MDI of any part of a Facility. Individual Directorate MDI scores are maintained within the database to help identify critical infrastructure which may be otherwise missed by rating buildings as a whole.

Per Executive Order 13327, MDI assessments are converted into broad groupings which are reported the the General Services Administration. Currently, these categories are:

- Mission Critical
- Mission Dependent
- Not Mission Dependent

Not Mission Dependent facilities are implicitly candidates for disposition.

Table 4 MDI Rating Scales

MDI Scores Mapped to Risk Severity and Federal Real Property Council Mission Criticality Rating

Mission Dependency Index Score	Risk Severity Descriptive Term	Federal Real Property Council Mission Criticality Rating
86 - 100	Critical	Mission Critical
71 - 85	Significant	
55 - 70	Relevant	Mission Dependent
10 - 54	Moderate	
0 - 9	Low	Not Mission Dependent

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MDI Reports

At the time this User Guide was prepared, there were two standard MDI reports. These basic reports DO NOT support the type of analysis recommended in this user guide, so an ad hoc report must be generated until a system request is approved and a new standard report is prepared. The current standard reports are:

1. **FCI - MDI Data (End User Procedure)**
2. **MDI Report: Mission Dependency Index (End User Procedure)**

https://bwprod01.ifmp.nasa.gov/SAP/BW/BEx?sap-language=EN&cmd=ldoc&TEMPLATE_ID=ZX01A_VIEW_QUERY_RO

Increasing Use of MDI

While NASA included the MDI as a significant innovation in its Asset Management Plan and has taken steps to fully implement the metric among its entire real property portfolio, it has only tepidly applied the metric toward achieving the stated objectives. MDI should be more fully used in considering both strategic and tactical alternatives regarding facilities.

Based upon repeated and regular contacts with the Center staff charged with updating and maintaining the MDI, the data provides a reasonably accurate assessment of the relative value of real property assets. The findings of this assessment are:

1. Scores are widely distributed and there is no obvious pattern of scoring facilities

excessively high. The actual scores are well spread.

2. The facilities rated as CRITICAL via the MDI criterion (a score of 85 or more) and with a LOW FACILITY CONDITION INDEX (i.e. 1 or, 2) are correctly assessed. This conclusion is based upon a sample of records which were sent to Centers for review. Centers reported that repairs were underway or being planned.

3. For purposes of reporting to the Federal Real Property Council, NASA defined MISSION CRITICAL as the combined total of the MDI CRITICAL and SIGNIFICANT categories. At the time this report was prepared, there were 1288 facilities in this category. NASA defined MISSION DEPENDENT, NOT CRITICAL as the facilities with an MDI score between 10 and 70. There were 2265 facilities in this group. Facilities which are coded as Abandoned, Mothballed, Standby or with an MDI score of 9 or less are in the NOT MISSION DEPENDENT class. 741 facilities were coded NOT MISSION DEPENDENT.

5. Most active facilities located on Centers have been assessed, although some of the facilities initially assessed in 2005-2006 have not been revalidated. The facilities for which scores still need to be validated are primarily located at JPL and LARC. GRC has completed its review, although not all information has been added to the database. JPL has verbally indicated satisfaction with its initial assessments. LARC intends to request assistance from the Navy in completing and validating its data. In some instance facilities which have not been assessed are currently listed as Active, but are actually designated for closure and perhaps demolition.

6. NASA has closed a surprisingly large number of facilities since 2002. From 1979 through 2009, a period of thirty years, NASA closed 1563 facilities, an average of 52.1 per year. From 2002 through 2009, a seven year period which commenced the “Repair by Replacement” and “Reduction of Excess Facilities” strategies, NASA closed 1022 facilities, an average of 146 per year.

7. NASA has added some facilities since 2002, but many of these are actually pre-existing facilities which were “found” during the DM Assessments and subsequently recorded in the Real Property Inventory database. Similarly, some of the “closures” were due to an effort to update the Real Property Inventory database to reflect facilities actually closed in previous years.

8. Use of MDI Score or MDI Descriptive Term for COF project selection seems to be increasing at the Centers based upon a limited number of discussions with Center staff. Guidance from FERPD would likely increase the use of the information even though such guidance might be limited to a general expression of how to use the information rather than a specific formula-based approach.

9. Some Centers appear to be beginning to address the use of the MDI Interuptability factor for facility operations risk management strategies. For example, GSFC is aware of opportunities to consolidate some of the functions which cannot be interrupted. In terms

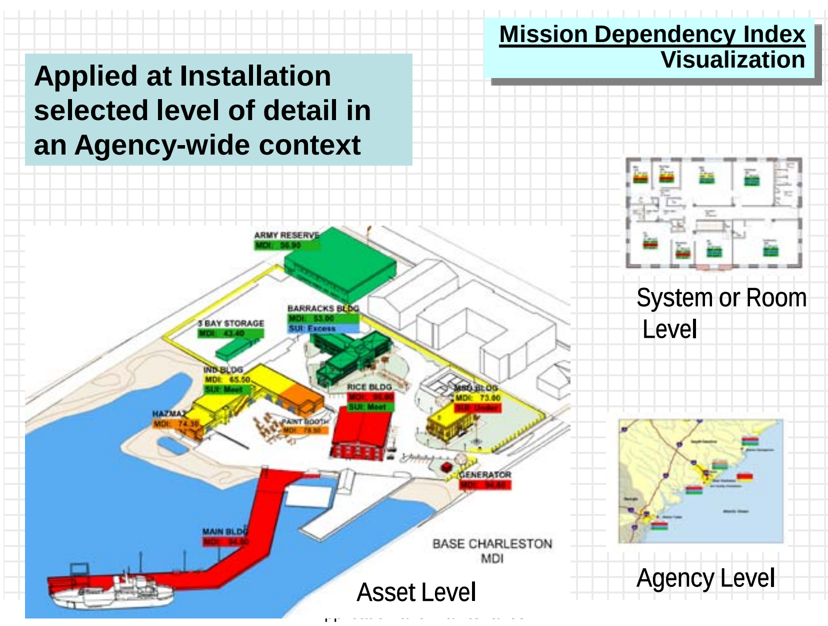
of facility utilization and master planning, the Interuptability of Function/Service factor suggests the need to consider the benefits of consolidating and relocating functions which cannot tolerate an interruption of support services. The consolidation of critical facilities into suitable locations will likely require changes in the workforce culture. Support from multiple levels of management may be required because such changes are beyond the scope of responsibility of the facilities engineering and real property community.

10. NASA should be reasonably confident in using the MDI five-level adjectival ratings as a basis for decisions related to long range planning and recapitalization.

The MDI metric can be used to greater benefit as indicated in the following examples:

Master Planning and Strategic Facility Planning. The Coast Guard has made extensive use of MDI for this purpose as indicated in Figure 3. In this example, MDI ratings are visually represented by colors associated with assets at the national, installation and sometimes even the individual room level. The same technique is applied to other asset metrics, helping the viewer to get an overall impression of the extent of problems and possible solutions via a consistent method which does not overly weight the value of numeric scores.

Figure 3 Visualization of MDI for Master Planning



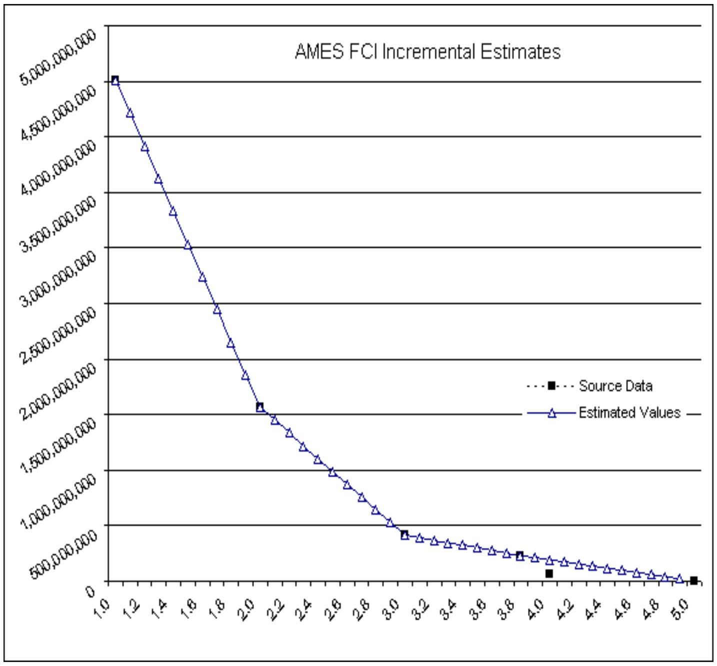
Repair/Replacement Analyses

The Deferred Maintenance Limits Study Phase II (NASW-02010 Task Order 006) report recommended Facilities Condition Index (FCI) and Deferred Maintenance (DM) goals for each of 9 systems within 42 facility categories as shown in Table 5. The nine systems are:

- Structure
- Roof
- Exterior
- Interior Finishes
- Heating/Ventilating/Air Conditioning (HVAC)
- Electrical Systems
- Plumbing Systems
- Conveyance Systems
- Program Support Equipment

Each system is rated from 5 (only normal maintenance required) to 1 (does not function as intended). These condition ratings are entered into a parametric estimating model that uses the facility current replacement value (CRV) as its basis. System CRV percentages have been established for each of the 42 facility categories. For example, electrical systems in laboratory and testing facilities make up a larger percentage of the overall building cost than electrical systems do in storage facilities. The System CRV percentages are derived from the Parametric Cost Estimating System, an accepted estimating tool derived from an evaluation of more than $40 billion of Federal construction projects, and the System Condition CRV Percentage tables are derived using *RSMeans™ CostWorks 2002 Version 6-12,* which is an industry accepted estimating system. For example, the System Condition CRV Percentage for a system with a 5 rating (only normal maintenance required) is 0%. As ratings become progressively lower, the percentages increase as shown in Figure 4 below.

Figure 4



Given the demands upon NASA resources, it is not reasonable to reduce deferred maintenance to zero. One proposal for a reasonable level of backlog has been to establish the goal as an amount equal to the annual recurring maintenance and repair spending. Another recommendation has been to provide resources at the level identified by the DoD Facility Sustainment Model. The Sustainment Model approach allows the capital program to concentrate on renewal of the asset base in an orderly fashion. More recently, the General Accountability Office, the Office of Management and Budget, the Federal Real Property Council, and NASA senior management have placed additional emphasis upon applying the concepts of Risk Management to as a means of assuring the capability of key physical assets to support the NASA Mission and Programs. Although architects and engineers generally address physical risks to facilities through the various building codes and standards, e.g. International Building Code, Fire and Life Safety Code, Seismic Code), the risks to agency mission and programs through functional obsolescence, deteriorating condition, and other factors are not directly addressed by the traditional design and construction codes and standards.

Table 5. Deferred Maintenance Categories and System CRV Percentages

M Cat	NASA_BLDG	STRUC	EXT	ROOF	HVAC	ELEC	PLUMB	CONV	INTF	EQUIP	SUM
1	R&D and Test Buildings	0.18	0.19	0.04	0.15	0.20	0.04	0.01	0.15	0.04	1.00
2	R&D Structures and Facilities	0.40	0.17	0.01	0.06	0.25	0.02	0.02	0.03	0.04	1.00
3	Wind Tunnels	0.30	0.05	0.01	0.01	0.15	0.01	0.01	0.01	0.45	1.00
4	Engine/Vehicle Static Test Facilities	0.38	0.03	0.01	0.04	0.26	0.01	0.03	0.02	0.22	1.00
5	Administrative Buildings	0.19	0.17	0.06	0.16	0.18	0.05	0.03	0.16	0.00	1.00
6	Training Buildings	0.18	0.20	0.05	0.12	0.21	0.05	0.01	0.18	0.00	1.00
7	Trailers	0.20	0.19	0.06	0.18	0.20	0.02	0.00	0.15	0.00	1.00
8	Storage Buildings	0.60	0.15	0.10	0.04	0.06	0.01	0.00	0.04	0.00	1.00
9	Storage Facilities	0.55	0.22	0.11	0.03	0.04	0.01	0.00	0.04	0.00	1.00
10	Fuel Storage Tanks	0.70	0.13	0.02	0.00	0.10	0.05	0.00	0.00	0.00	1.00
10.1	Specialized Liquid Storage Tanks	0.51	0.13	0.02	0.00	0.14	0.20	0.00	0.00	0.00	1.00
10.2	Fueling Stations & Systems	0.40	0.10	0.05	0.05	0.15	0.20	0.00	0.05	0.00	1.00
11	Magazines	0.33	0.30	0.05	0.06	0.15	0.02	0.00	0.09	0.00	1.00
12	Comm. & Tracking Buildings	0.21	0.20	0.05	0.16	0.18	0.05	0.00	0.15	0.00	1.00
13	Comm. & Tracking Facilities	0.55	0.10	0.02	0.05	0.26	0.00	0.00	0.02	0.00	1.00
13.1	Large Antennas	0.20	0.20	0.02	0.05	0.15	0.02	0.01	0.02	0.33	1.00
13.2	Small Antennas	0.50	0.30	0.00	0.00	0.10	0.00	0.00	0.00	0.10	1.00
14	Mission Control Operations Buildings	0.22	0.13	0.05	0.15	0.20	0.04	0.02	0.10	0.09	1.00
15	Lighting	0.17	0.00	0.00	0.00	0.83	0.00	0.00	0.00	0.00	1.00
16	Electrical Distribution System	0.39	0.03	0.00	0.00	0.58	0.00	0.00	0.00	0.00	1.00
16.1	Power Generation/Power Plant	0.30	0.10	0.05	0.10	0.39	0.01	0.00	0.05	0.00	1.00
16.2	Electric Substations, Switchgear & Transfer Yards	0.10	0.07	0.00	0.00	0.83	0.00	0.00	0.00	0.00	1.00
17	HVAC Distribution	0.30	0.10	0.00	0.00	0.33	0.27	0.00	0.00	0.00	1.00
17.1	HVAC Generation	0.20	0.10	0.05	0.35	0.10	0.15	0.00	0.05	0.00	1.00
18	Waste Water Collection & Disposal System	0.50	0.02	0.02	0.00	0.05	0.41	0.00	0.00	0.00	1.00
8.1	Waste Water Facilities & Treatment Plants	0.34	0.10	0.05	0.03	0.15	0.32	0.00	0.01	0.00	1.00
18.2	Storm drains, Ditches, Dams, Retaining walls	0.90	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.00	1.00
19	Potable Water Distribution System	0.38	0.05	0.02	0.00	0.05	0.50	0.00	0.00	0.00	1.00
19.1	Potable Water Facilities & Treatment Plants	0.25	0.05	0.05	0.03	0.24	0.37	0.00	0.01	0.00	1.00
20	Launch Pads	0.51	0.10	0.03	0.03	0.25	0.04	0.02	0.02	0.00	1.00
20.1	Launch support camera pads	0.80	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.00	1.00
20.2	Launch propellant & high pressure gas facilities	0.48	0.05	0.02	0.00	0.20	0.25	0.00	0.00	0.00	1.00
21	Pavement	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
22	Rail	0.95	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	1.00
23	Maintenance Facilities & PW Shops	0.20	0.14	0.06	0.13	0.30	0.09	0.00	0.08	0.00	1.00
23.1	Operational maintenance. Facilities	0.20	0.14	0.06	0.13	0.28	0.09	0.02	0.08	0.00	1.00
24	Other Buildings	0.22	0.15	0.12	0.10	0.15	0.11	0.00	0.15	0.00	1.00
25	Other Facilities	0.71	0.10	0.02	0.05	0.10	0.01	0.00	0.01	0.00	1.00
26	Land & Easements	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
27	Compressed Air Distribution	0.50	0.00	0.00	0.00	0.10	0.40	0.00	0.00	0.00	1.00
27.1	Compressed Air Generation	0.25	0.10	0.05	0.05	0.15	0.35	0.00	0.05	0.00	1.00
28	Prefab buildings, various uses	0.18	0.17	0.05	0.15	0.15	0.15	0.00	0.15	0.00	1.00
29	Berthing & Housing	0.15	0.17	0.09	0.16	0.18	0.07	0.02	0.16	0.00	1.00

The DM goals were established by a group of professional engineers with many years of facilities experience using their knowledge of NASA facilities operations and good engineering judgment to arrive at realistic system condition ratings for each of the systems within each facility category. Using these goal ratings, a tool based on the DM model generated an FCI goal for each category. Applying these FCI goals to each asset within the Real Property Inventory, the tool determined that NASA should establish an FCI goal of 4.3 for the entire Agency portfolio. These facility condition goals were established to support Agency facility managers in their efforts to ensure that facilities can fully support NASA's missions, operations, safety and human health and comfort commitments under the assumption that all active facilities of the same type are equally important in contributing to the mission as shown in Table 6. Table 7 shows the summary FCI for the most prevalent types of facilities assuming they are also "Critical".

Table 6 Recommended Target Condition Rating for "Critical" R&D and Test Buildings

R&D and Building	CRV 27 of NASA $6,12
Syste	**Condition Ratin**
Structur	4
Roo	4
Exterio	4
Interior	4
Electrica	5
HVA	5
Plumbin	4
Conveyance	5
Pgm Support	5
FCI	**4.**
FY03 FCI	**3.**

Table 7. Original DM Model Recommended FCI Goals for Five Largest Categories and the Agency Total Based Upon CRV

DM Category	NASA Facility Description	Facility Count	FY03 CRV($M) Total	Category % of NASA CRV	FY03 Actual FCI	Recommended Minimum FCI Goal	% CRV of DM Goal per Category
1	R&D and Test Buildings	530	$6,123	27%	3.8	4.4	8%
3	Wind Tunnels	74	$2,813	12%	3.8	4.6	7%
24	Other Buildings	440	$1,520	7%	3.0	4.0	31%
21	Pavement	235	$1,456	6%	3.5	4.0	7%
5	Administrative Buildings	278	$1,446	6%	3.8	4.4	9%
	NASA Total	5778	$22,762	100%	3.6	4.3	10.0%

MDI provides the basis for further classifying facilities by their relative contributions to missions. Table 8 shows this concept using recommended condition limits which are explained below.

Table 8. Recommended FCI for MDI Facilities by DM Facilities Category[a]

DM Cat	NASA Facility Description Category	FY03 FCI[a]	Goal FCI[b]	Minimum FCI for MDI CRITICAL[c] Facilities	Minimum FCI for MDI SIGNIFICANT[d] Facilities
15	Lighting	2.9	4.8	4.5	4.3
16.2	Electric Substations, Switchgear & Transformer Yards	3.8	4.8	4.5	4.3
20	Launch Pads	4.0	4.8	4.5	4.3
3	Wind Tunnels	3.8	4.6	4.3	4.1
4	Engine/Vehicle Static Test Facilities	3.4	4.6	4.3	4.1
13.1	Large Antennas	4.2	4.6	4.3	4.1
16	Electrical Distribution System	3.4	4.6	4.3	4.1
14	Mission Control Operations Buildings	4.0	4.5	4.2	4.0
20.2	Launch propellant & high pressure gas facilities	3.5	4.5	4.2	4.0
23.1	Operational maintenance facilities	3.2	4.5	4.2	4.0
27.1	Compressed Air Generation	3.5	4.5	4.2	4.0
5	Administrative Buildings	3.8	4.4	4.1	3.9
10.2	Fueling Stations & Systems	4.0	4.4	4.1	3.9
16.1	Power Generation/Power Plant	3.8	4.4	4.1	3.9
2	R&D Structures and Facilities	3.4	4.4	4.1	3.9
1	R&D and Test Buildings	3.8	4.4	4.1	3.9
6	Training Buildings	3.4	4.3	4.0	3.8
10.1	Specialized Liquid Storage Tanks	4.6	4.3	4.0	3.8
12	Communication and Tracking Buildings	3.8	4.3	4.0	3.8
13	Communication and Tracking Facilities	3.9	4.3	4.0	3.8
17	HVAC Distribution	3.7	4.3	4.0	3.8
10	Fuel Storage Tanks	3.9	4.2	3.9	3.7
13.2	Small Antennas	4.2	4.2	3.9	3.7
18.1	Waste Water Facilities & Treatment Plants	4.0	4.2	3.9	3.7
17.1	HVAC Generation	3.7	4.1	3.8	3.6
18	Waste Water Collection & Disposal System	3.6	4.1	3.8	3.6
22	Rail	3.0	4.1	3.8	3.6
7	Trailers	3.5	4.0	3.7	3.5
8	Storage Buildings	3.8	4.0	3.7	3.5
9	Storage Facilities	4.0	4.0	3.7	3.5
11	Magazines	4.0	4.0	3.7	3.5
19	Potable Water Distribution System	3.6	4.0	3.7	3.5
19.1	Potable Water Facilities & Treatment Plants	3.8	4.0	3.7	3.5
20.1	Launch support camera pads	4.1	4.0	3.7	3.5
21	Pavement	3.5	4.0	3.7	3.5
23	Maintenance Facilities and PW Shops	3.3	4.0	3.7	3.5
24	Other Buildings	3.0	4.0	3.7	3.5
27	Compressed Air Distribution	2.0	4.0	3.7	3.5
28	Prefabricated buildings, various uses	4.1	4.0	3.7	3.5
29	Berthing & Housing	3.7	4.0	3.7	3.5
25	Other Facilities	3.9	3.9	3.6	3.4
18.2	Storm Drains, Ditches, Dams, Retaining walls	3.2	3.8	3.5	3.3
NASA Averages		**3.6**	**4.3**	**4.0**	

Notes to Table 8
[a]The FY03 FCI is used because this is the database used for the Deferred Maintenance Limits Study – Phase II Report- June 30, 2004, page 28.
[b]Goal FCI" – This method of analysis does not attempt to establish a date for attaining the goal. The date the goal would be attained depends upon the amount of funding available.
[c]2007 Deferred Maintenance Report computed the standard deviation of FCI values at 0.3. For the purpose of establishing an "FCI for CRITICAL (MDI 81-99) Facilities" the standard deviation value of 1.0 has been subtracted from the Goal FCI.
[d]2007 Deferred Maintenance Report computed the standard deviation of FCI values at 0.3. For the purpose of establishing an "FCI for SIGNIFICANT (MDI 61- 80) Facilities" the standard deviation value of 1.5 has been subtracted from the Goal FCI.

Recommended Method for Analysis

Use of the MDI to determine a reasonable level of facilities' conditions may be based upon incorporating the concept of statistical control theory with the risk management concepts of the MDI and the empirical observations used in the Deferred Maintenance condition assessment model. Given the assumption that applying Pareto's Rule to risk management is logical, it makes sense to use the DM, MDI and CRV values in combination as a screen to identify facilities which are very importance to the NASA mission, are costly to replace and are below some threshold condition level. As indicated in Figure 6, the Risk Severity scale places facilities with an MDI score of 86 – 100 in the CRITICAL category, and those with a score of 71 – 85 in the SIGNIFICANT category. These scores were constructed from the perspective of NASA program and project users of NASA facilities. They total approximately 750 and 1500 facilities respectively. Pittinger [1999] recommended applying Pareto's Rule to high replacement value assets which would yield about 600 NASA's facilities when applying a risk management criterion based upon the replacement value alone. Toufectis [2010] has applied a similar approach.

Using the DM value alone as a risk management criterion with a one-tail test for active facilities with condition scores of one standard deviation below the mean would examine approximately 750 facilities with a condition score below 3.4. However, many of the facilities which have low condition scores may also have low MDI scores. A better approach might be to examine those MDI critical facilities which have a condition score value which is 1.0 standard deviation below the goal for their facility type or 1.5 deviations below the goal for those with an MDI significant rating. The selection of the value of the standard deviation to use for screening is somewhat arbitrary. Traditional statistical quality control models typically use 2 or 3 standard deviations, but one standard deviation using a one-tail test yields about 16% which is close to the 20% used by a Pareto Analysis. The relaxed deviation value for MDI significant ratings balances the relaxation of the MDI criterion in keeping with the overall Pareto concept. The recommended FCI goals and screening values are shown in Figure 9. By combining the DM and MDI using these criteria, the number of facilities subject to a more intensive risk management analysis is reduced to approximately 100 – 250. Since the MDI includes some consideration of replacement value, adding this factor into the screening criteria would not reduce the number of facilities by less than 80%., but a 50% reduction might be a reasonable estimate. Therefore, approximately 50 to 125 facilities would be subject to consideration for additional risk analysis.

Some facilities screened for additional risk analysis consideration may have repair or renovation projects in planning, design or construction. Others may have been designated for an alternative future use or for inactivation. These facilities would be eliminated from further risk assessment consideration.

For those facilities which remain under consideration, it may be that the goal FCI or the MDI have been set too high. Although these goals were set by experienced engineers and reviewed by HQ staff, they were never reviewed by program/project users of the facilities. Similarly, although the MDI scores were set through carefully structured interviews and questions with program/project users of facilities, the use of the MDI may indicate that some questions were not answered quite correctly. In the first situation, an adjustment in the goal FCI may be appropriate. In the second situation, revision answers to MDI questions may be appropriate.
Any facilities which remain under consideration following these basic reviews should be considered candidates for placement on the NASA Active Risk Management System.

This concept was tested using the NASA Deferred Maintenance Model facility category 1, R& D and Test Buildings, a category representing about 27% NASA CRV. The FY08 DM score for these 400+ buildings was 3.8 versus a goal based upon treating all the facilities as Mission Critical of 4.4. When the 5 level MDI scale is applied to these facilities with the additional rule that buildings which exceed the minimum lower limit for their MDI category shall be sustained at the existing FCI value, the recommended DM score is reduced to 3.9, a very modest incremental improvement. If this MDI based modification of the FCI goal is completed for all of the active assets, the overall NASA goal will be reduced to very slightly above the current value.

The next step in this analysis is to examine about 300 of the 1100 facilities which are considered essential to NASA's future plans. The 300 represent about 90% of the NASA CRV.
The MDI categories used in this analysis were selected by HQ staff. The MDI values for individual facilities are those computed in the 2008-2009 update. In general, Centers reduced the number of facilities placed in the CRITICAL category because they recognized that alternatives existed should the facilities become inoperable and Centers had also updated the Real Property Information System by more facilities which will be closed or demolished. These facilities were excluded from the study.

The statistical control limits used in this analysis are subject to review and possible adjustment.

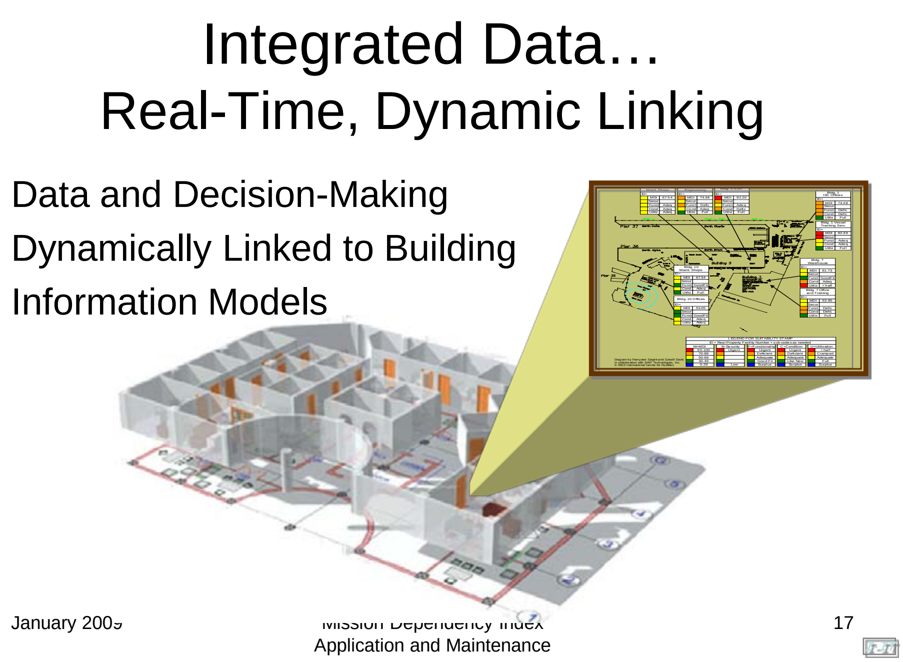
Note Regarding DM Model

Pittinger recommended further reducing the cost of gathering deferred maintenance data by applying the "Pareto Rule" (Securing 80% of the result for 20% of the cost, etc.) by inspecting the group of facilities that represent the majority of an agency's CRV and then extrapolating for the remainder of the assets. From a 1997 Facilities Investment Study, he noted that NASA's most expensive 675 facilities equated to 88% of NASA's CRV. However, in order to address the concerns of the Comptroller with respect to the audit findings, it was determined that all facilities should be assessed for the initial DM deployment. In subsequent years, NASA has elected to continue the annual assessment of all assets. One benefit of this annual assessment approach is that various possible errors in the real property database are discovered and addressed. Another benefit is that minor errors in condition assessment are corrected. The growing confidence in the NASA Real Property Information System data is apparent in the Deferred Maintenance Reports for 2002 through 2007 comments upon the corrections in the database and demonstrates the continuing reduction in the variability of the condition assessments. The reports support the conclusion that it is appropriate to use the average condition of active NASA facilities value of 3.7 with a standard deviation of 0.3 for analysis purposes.

The Future Incorporation of Building Information Modeling

As NASA adopts Building Information Modeling, it will be possible to incorporate MDI and other metrics into real time management of facilities at the individual facility component level. Currently there is a great deal of potentially useful information gathered during the COF planning phase which is transformed into the design of a facility, but the information is not transferred to the owner/manager in a database structure which can be maintained economically. Through the changing technology developing as open data standards and building information modeling, it is now possible to overcome these limitations. Further, real time and dynamic information from building control systems, maintenance management systems, and other databases is now feasible as indicated in Figure 5. Maintaining optimal use of constructed assets is becoming a possibility.

Figure 5



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