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Light Water Reactor Sustainability Program

Automated Work Package: Conceptual Design and Data Architecture

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SUMMARY

The automated work package (AWP) is one of the projects under the Advanced Instrumentation, Information, and Control Systems Technologies pathway of U.S. Department of Energy's Light Water Reactor Sustainability Program.

An AWP is an adaptive and interactive work package that intelligently drives the work process according to plant condition, resources status, and user progress. The AWP aims to enhance efficiency, enhance human performance, and reduce human errors by automating several manual tasks of the work process.

Electronic work packages (eWPs) are work packages that rely, to various extents, on electronic data processing and presentation. AWPs are the logical evolution of eWPs. They are envisioned to incorporate advanced technologies and innovations of the future and address unresolved deficiencies in the work process of a nuclear power plant.

As an initial step in designing an AWP, a scenario of the possible future work process without any current technology restrictions is developed. The approach followed to develop this scenario targeted every stage of the work process execution.

The scenario development resulted in 50 advanced functions that can be part of AWP. To rank the importance of these functions, a survey was conducted that involves several U.S. nuclear utilities.

The survey was aimed at determining the current need of the nuclear industry with respect to the current work process (i.e., what the industry is satisfied with and where the industry envisions potential for improvement). The survey evaluated the most promising functions that resulted from the scenario development. The survey demonstrated a significant desire to adopt the majority of these functions.

The results of the survey are expected to drive Idaho National Laboratory AWP research and development. In order to facilitate this mission, a prototype AWP is needed. Because the majority of earlier efforts focused on the front-end aspects of AWP, the back-end was researched and developed in this effort.

The back-end design explored data architecture aspects. It was realized through this effort that the key data architecture principles of this design are hierarchy, segregation based on functionality, data replication, representation of the work package flow of execution, the use of properties, and the flexibility of interfacing the back-end to the front-end.

The data architecture was evaluated by incorporating an example work order from a nuclear power plant. Implementation resulted in the rearrangement of the work order information to fit the data architecture. This highlighted several work order improvements and AWP benefits.

The envisioned path forward for AWP research and development is to interface the already existing AWP front-end with the recently developed back-end in order to develop a proof-of-concept prototype. The prototype will be used to study a selected number of functions. Function selection will depend on

nuclear industry survey results and the feasibility of developing such functions at the current state of technology.

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ACRONYMS

AWP	automated work package
DBT	database table symbol
eWP	electronic work package
HF	human factors
II&C	instrumentation, information, and control
INL	Idaho National Laboratory
M&TE	measurement and test equipment
MTM	many-to-many
OTM	one-to-many
OTO	one-to-one
RFID	radio-frequency identification

Automated Work Package: Conceptual Design and Data Architecture

1. INTRODUCTION AND BACKGROUND

Work processes in the nuclear power industry consist of a defined set of tasks that are executed in a fixed or flexible order, require specific resources, and meet overall work objectives. The tasks are highly dependent on procedures that guide field workers through the work stages. These stages are compiled into typically large work packages that include work orders, forms, and reference documents. Work package development and compilation is performed by a procedure writer or planner. Procedures are written in accordance with an industry-specific standard (Procedure Professionals Association 2011). Once a work package is compiled, the schedulers allocate plant resources to the work package and schedule its execution. The work package and resources are then acquired by field workers with the support of other relevant plant organizations.

Use of work packages in nuclear power plants has demonstrated a proven record of success in terms of maintaining plant safety. However, the recent plan for the nuclear industry to extend their operating licenses to 80 years motivated research and development of potential process improvements to realize benefits that were not explored earlier. This resulted in this effort, along with other efforts, as part of the U.S. Department of Energy's Light Water Reactor Sustainability Program to develop capabilities needed for long-term sustainable plant operation.

The Light Water Reactor Sustainability Program is a research and development program that is sponsored by the U.S. Department of Energy and is performed at Idaho National Laboratory in close collaboration with industry. One of the key missions of the program is to develop several pilot projects for research and development and industrial evaluation. The effort to automate parts of the work process through prototype development and pilot evaluations that are targeted in this effort is one of this program's projects as described in Hallbert and Thomas (2015).

Work process improvement can be utilized by applying the science of human factors (HF) in design of work packages and by using the advancements of instrumentation, information, and control (II&C) technologies in automating the work package processes. The synergy of both areas is achieved by attempting to resolve work process deficiencies through HF techniques and then resorting to II&C techniques for the unaddressed or unresolved deficiencies. The overall result of this approach is enhanced safety and higher efficiency.

Implementation of advanced HF and II&C techniques in the design of a work process necessitated evolution of the conventional paper-based work packages to advanced electronic versions of work packages. This resulted in the guidelines developed in Farris and Medema (2012). Idaho National Laboratory has realized the safety and economic benefit of this type of work packages (Thomas and Lawrie 2015), and explored, through the Light Water Reactor Sustainability Program, the best means for the industry's planned or ongoing efforts to adopt various levels of electronic versions of work packages. This included developing prototypes of new capabilities, performing human performance studies, and exploring challenges that industry might face and the means to resolve them.

Electronic work packages (eWPs) are work packages that rely, to various extents, on electronic data acquisition, processing, and presentation. Electric Power Research Institute introduced various functions of this type of work package (EPRI 2015). Refinement of the requirements of eWPs is an ongoing effort. These requirements aim to incorporate currently available or soon-to-be available capabilities in the work process. Automated work packages (AWPs) are the logical evolution of eWPs. Their initial requirements were defined in Agarwal et al. 2014. They are envisioned to incorporate the advanced automation technologies and innovations of the future and address the work process deficiencies that are not resolved by eWPs (Figure 1). This effort aims to describe an AWP using the following stages of analysis:

1. Performing a deficiencies or gaps analysis study on the current work processes.
2. Determining the gaps that are addressed by eWPs.
3. Determining the remaining gaps that are not resolved by eWPs.
4. Identifying new technologies or functions to address the remaining gaps.

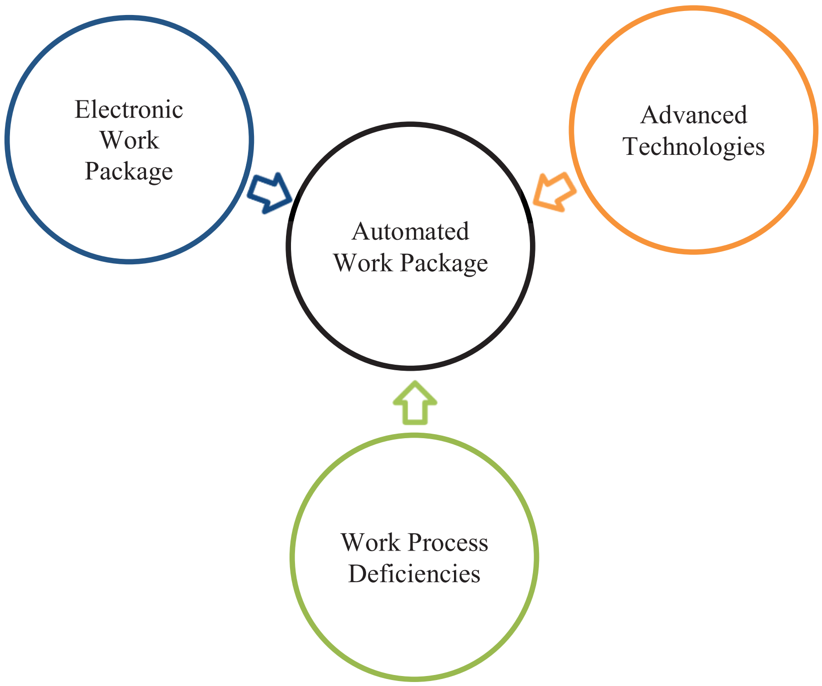

Figure 1. Elements contributing to development of AWPs.

Steps 1 and 2 have been investigated in earlier and ongoing efforts (EPRI 2015). Section 2 of this report targets Steps 3 and 4 and defines the envisioned AWP functions. Because nuclear industry is the ultimate user of this research, the identified functions of AWPs are surveyed by nuclear power utilities to confirm their potential benefit by the industry. This is described in Section 2 of this report. Upon identifying the AWP functions, the data architecture was designed to accommodate the work package layout along with its developed functions. This is presented in Section 3. The aim of the data architecture is to serve as an example for industry to adopt and to develop lessons learned. In addition, the data architecture aims to create the foundation to which earlier and future AWP function development can be integrated for systematic and modular AWP prototype development. After the data architecture is designed, an example of a work order implementation is presented in Section 4. This example highlighted the potential improvements of the work order that result from the systematic data acquisition, processing, presentation, and use in the AWP. For the remainder of this report, the procedure writer and planner will be referred to as the planner.

2. ENVISIONED AUTOMATED WORK PROCESS

The ultimate vision of an AWP is to fully automate the work process cycle from the work request initiation to archiving, especially targeting areas where human factors errors are critical. To introduce the new vision and to ensure consistency, the work package process description used in the Electric Power Research Institute's eWP (EPRI 2015) will be used for introducing AWPs.

The definition of AWPs is best illustrated through scenario development. This section starts by introducing the scenario. The scenario is used to develop a list of functions that are proposed for AWPs.

These functions were surveyed by the industry. The survey process and results are discussed in this section.

2.1 Scenario of the Future

The scenario introduced in this section sustains the current flow of the work package process. The envisioned scenario would utilize staff-assigned mobile devices equipped with an AWP platform that advises and guides the field worker to the following work destination in addition to the scope of work. The AWP will play the role of being the worker's day-to-day mentor.

2.1.1 Initiation of Work Request

In addition to the manual and/or remote initiation of work requests, AWP would facilitate a more efficient and error free automatic initiation of work requests. This vision would require plant equipment that is smart to know and report the equipment maintenance need. This is achieved by instrumenting the plant equipment with smart instruments. Smart instruments do exist in various industries today and their benefit for predictive maintenance has been utilized. For example, modern turbines are often equipped with vibration and temperature sensors to detect any deviation from the equipment norm. Means of equipping plant components that do not have smart diagnostics and prognostics are being explored (Agarwal et al. 2014; Agarwal et al. 2015). Other maintenance prediction methods rely on smart plant state evaluation. Discrepancies in instruments readings can be used as an indication of a process equipment malfunction. For example, a pipe leak can be detected by comparing the flow in and out of the pipe. This area of research has also been advancing (Cetiner 2015). If these areas of automated diagnosis and prognosis are coupled to the work request system, work requests can gradually move from the manual conventional methods of initiation into both manual and automated work request initiation process.

It is also envisioned that manual and/or remote initiation of work requests would rely on simplified and automatic template data population of work requests. All plant equipment will have its own list of potential work request initiation templates. The list will be accompanied by a probability of occurrence of the various failure modes. This probability will be based on diagnosis information from smart instruments, a plant state diagnosis system, and the historical behavior of equipment. The field worker will need to select the applicable work request from a list and then the rest of the information would be populated. The field worker will be given the option of editing any part of the work request or add a comment if needed. This work process automation results in the following AWP functions:

Function 1: Automatic creation of a work request by systems, schedules, and current work packages.

Function 2: Integration of smart plant equipment that perform self-diagnosis and prognosis into the work request creation process.

Function 3: Integration of intelligent plant discrepancies identification systems into the work request creation process.

Function 4: Association of work requests with equipment failure modes and their associated probabilities of failure.

Function 5: Simplified and automatic template data population of work requests.

2.1.2 Screen Work Request

Once a problem is identified, its information is instantaneously and automatically passed to operations and relevant plant organizations, depending on the initiated work request. Information such as priority and impact would be associated with the work request and would be evaluated against the current state and risk level of the plant. Operations and other relevant organizations are presented with a summary and detailed description of the feasibility of executing the work request, the needed requirements, and the ideal environment and time to execute the job. Achieving this task would require the capability to evaluate the impact of work on the plant and plant risk estimation tools. This work process automation results in the following AWP function:

Function 6: Automatic evaluation of the impact of work on the plant and plant risk estimation tools.

2.1.3 Work Package Creation and Scheduling

In the envisioned AWP, every work request template will be associated with a work package. If the required work package has not been created before, the planners will only need to create it once. Any future use of the work package would require review of the work package only. This review would not involve tasks that can be automated (such as ensuring that the latest version of documents has been included); these tasks are automatically performed by the AWP.

Work package creation will also be automated. The planner does not need to explicitly specify the list of materials, documents, tools, and other resources of a work package. These resources would be associated with the steps (or instructions) of a work package and would be automatically populated to the work package once the step is included in the work package. This results in improved work package compilation, quality, and speed.

Once the work package has been compiled and loaded, a smart scheduling capability will re-verify the feasibility of performing the work in the current operational state by acquiring data from various plant information systems, including the plant enterprise asset management system, and the plant status as was performed in Oxstrand et al. 2015a. The smart scheduling capability will acquire all plant work requests and their work package steps, along with their priorities from various areas of the plant, and evaluate the optimal sequence and time slots to perform them. The optimal time for performing the task will depend on the operational status of the plant; the priority of the request; the availability of logistical requirements such as manpower, materials, and tools; and the resulting aggregated increase in plant risk. A probabilistic assessment of the effect of any delays or interruption of the request on the plant risk would also be performed. Other less trivial factors (such as weather, time of day, and the field worker's stress factor) will also be evaluated to determine the best resources and time for performing the work. The smart scheduling tool will continuously evaluate the progress of ongoing work processes and update the plan accordingly.

The smart scheduler will place the tasks in the field worker calendar and reserve other needed resources at the scheduled time. Once the work package execution time is reached, the reserved work package resources, including manpower, tools, and materials, are automatically released and assigned. Document revisions are automatically verified and polled from records and archives if needed. This work process automation results in the following AWP functions:

Function 7: Automatic allocation of work packages to work requests.

Function 8: Automatic population of work package information and properties from the work package instructions.

Function 9: Automatic acquisition of plant information.

Function 10: Real time plant risk models update based on current work packages status.

Function 11: Comprehensive smart scheduling capability to determine the optimal sequence of work package steps execution in the plant.

Function 12: Automatic allocation, reservation, and release of work package resources.

Function 13: Automatic verification and acquisition of documents.

2.1.4 Pre-Implementation Walk Down

The need for a pre-implementation walk down will be associated with the work package and would be automatically requested from the relevant parties to assemble the walk-down team near the work order's execution location. The optimal time is automatically set according to the involved parties' schedule.

Walk-down instructions will advise the walk-down performers on what to look for in preparation for the job, and a set of evaluation questions will be asked to confirm the work package scope can be executed as planned or whether it needs to be assigned a new time slot or resources. This implies that the walk-down process will be incorporated in an instructions form in the work package. This work process automation results in the following AWP functions:

Function 14: Associating the need for a walk down with the work package.

Function 15: Systematic instructions-based walk-down process incorporated in the work package.

2.1.5 Supervisor Assigns Work Package to Craft

Review of field worker qualifications and their experience in performing similar tasks will be automated. The AWP will evaluate worker qualifications with respect to work package scope in a manner similar to EPRI (2014). In the context of AWP, every instruction or process of the work package will be associated with certain qualifications. If the field workers' qualifications meet part of the required qualifications, multiple field workers can be assigned to individual tasks. Automated allocation will also involve factors such as historical behavior of the field worker in performing certain instructions, stress factor of the field worker, training record, availability, hazards qualifications, impact, and criticality of the task. Automated decision making of the best field worker for the job is presented to the supervisor to review, edit if needed, and confirm.

If training is needed, the AWP will define the training module for the field worker to perform the job. Once the field worker has been confirmed, the training is scheduled to the field worker. If the training is automated by means of audio, video, and augmented or virtual reality, it is loaded at the time of the training. If the training is human-based, the trainer's work schedule is updated with a suitable time slot for the training to occur. In the envisioned scenario, the smart scheduling capability would find a slot to meet the schedules of both the trainer and all trainees.

If the AWP decides the field worker is fit, but needs some refreshment or his/her capability to perform the job is questionable, a random set of task-specific stored questions will be automatically presented. If the questionnaire deems that the field worker is unqualified for the task, the field worker is either trained or replaced. This work process automation results in the following AWP functions:

Function 16: Automatic manpower allocation based on historical performance, field worker status, qualifications, training records, availability, hazards qualifications, impact, and criticality of the task.

Function 17: Training through audio, video, and augmented or virtual reality.

Function 18: Task-specific questions to validate and refresh field worker readiness.

2.1.6 Holds and Pre-Job Brief

Once the field worker is assigned, holds are automatically reviewed by the AWP; the supervisor is requested to approve the review in order to clear the hold.

The workers' pre-job briefing is conducted based on the scope of the work package. The AWP decides on the key points that need to be mentioned in the pre-job briefing, including the job execution plan, hazards, cautions, warnings, notes, historical issues, projected execution time and duration, and any specific comments the supervisor adds. The pre-job briefing could be conducted through videos or other advanced technologies (such as augmented or virtual reality). The worker would be asked a few questions at the end of the briefing if needed to ensure the worker's awareness of the most critical information. Automation of this work process results in the following AWP functions:

Function 19: Automatic hold review and removal or notification for removal.

Function 20: Automatic determination of key points to mention in the pre-job briefing based on the work package scope.

Function 21: Pre-job briefing by means of video, augmented, or virtual reality.

Function 22: Tracking the historical common issues with work package activities.

Function 23: Using the historical execution time of all work package activities.

2.1.7 Measurement and Test Equipment, Tools, and Spare Parts

The measurement and test equipment (M&TE), tools, and spare parts used in the plant will be equipped with radio-frequency identification (RFID) tags that are linked to the AWP. Once they are picked up, AWP will automatically ensure the field worker has the appropriate M&TE, tools, or parts to perform the task by tracking their location. AWP will ensure the field worker does not forget a needed M&TE, tools or spare parts, the field worker did not pick up the wrong M&TE, tool, or spare part, and that M&TE, tools, and spare parts are not forgotten or misplaced in the plant. AWP will also make sure M&TE has been calibrated and is suitable for the work package in terms of nature of measurements, range of measurements, and accuracy.

AWP will also ensure the field worker has the needed safety equipment. For example, if the task is performed in a radiation environment, RFID and wireless enabled radiation detectors will be provided to the field worker as part of the required equipment. These detectors will communicate current exposure to the AWP and a central dose tracking system. They will alert the field worker as soon as an abnormality occurs or if the field worker dose, which is based on historical field worker data, is getting close to the allowed limit. The radiation safety officer will have an active online log of all field worker exposures during any point of time and will have the capability to remotely stop or suspend any work package if needed.

M&TE and tool tracking would also enable better utilization of the available resources. For example, once a task requiring certain M&TE or tool is completed, there is no need for another field worker to wait for the work package to be completed to return the M&TE or tool. Other work packages can use it as soon as it is released by the AWP task that is using it. This work process automation results in the following AWP functions:

Function 24: Smart and RFID-enabled M&TE, tools, and spare parts.

Function 25: Automatic calibration tracking and assurance of proper M&TE use.

Function 26: Automated safety compliance and enforcement techniques.

Function 27: Tracked and optimized M&TE and tools use.

2.1.8 Walk Down Clearance (Tag Out) and Operations Permission to Start

As the field worker heads toward the work activity location, AWP and plant equipment location detection functions will automatically proceed with tag out and clearance requests. An electronic tagging system will be implemented to manage the tag out and tag in processes. If a tag out needs to be performed on certain plant equipment, an electronic indication at the equipment location will change to indicate the new tagged out status when the work is scheduled to start. This will automatically update the tag out database, which keeps track of all tagged out and tagged in equipment. Operations are then automatically requested for clearance after the AWP verifies plant conditions allow the job to be performed. Operations will remotely confirm the clearance and the clearance database is updated automatically. The field worker is then notified of the permission to proceed with the work activity. This permission can be accompanied by an operations electronic hand written signature and date for critical tasks. This work process automation results in the following AWP functions:

Function 28: Use of AWP devices location tracking in scheduling and progress tracking.

Function 29: Use of plant equipment location definition in scheduling and progress tracking.

Function 30: Electronic tagging system displays.

Function 31: Automatic tag out and tag in.

Function 32: Automatic notification and clearance requests to supervisors, operations, and other relevant entities.

Function 33: Remote notification of permission to start.

2.1.9 Perform Work Activity

Upon starting the work activity, the field worker's AWP device location will be used to confirm the field worker is at the right equipment. Once the work starts, a set of computer-based procedures will guide the operator through the work (Oxstrand et al. 2014; Oxstrand and Le Blanc 2015; Oxstrand et al. 2015b; Oxstrand and Le Blanc 2016). The level of detail of the procedures will depend on the field worker's qualification and the criticality of the performed task. The field worker will be assisted by voice commands and instructions to help the field worker utilize both hands if needed. The time to complete each task will also be tracked. If a task takes significantly less or more time than usual, the field worker and supervisor are alerted, because this indicates a possible issue or human error. Operations, the supervisor, safety officers, and all relevant plant entities will have full view access to the field workers' progress. The supervisor will also have the capability to request video monitoring of a task. This can be implemented through various techniques (such as a safety helmet-held camera). If an issue occurs during work execution, the field worker will have the possibility to record through text, video, or audio the issue and immediately and remotely report it to the supervisor. The field worker will be warned of previous work package issues at a specific stage or on similar equipment to avoid common issues faced in the past. Steps where human errors are common will automatically populate warnings to alert the field worker. If supervisor presence is required for a certain step, AWP will automatically notify the supervisor ahead of time of this need and add the task to the supervisor's work schedule. A projection of task completion time will also be generated and sent to the smart scheduling tool to ensure the scheduling is optimized. The field worker will be able to provide feedback or review any part of the work package including steps, documents, warnings, plant components, trainings, spare parts, tools, and M&TE at any stage of the work package. This information will be used to evaluate and improve AWP performance. This work process automation results in the following AWP functions:

Function 34: Location-based verification of the equipment to perform the work on.

Function 35: Use of computer-based procedures.

Function 36: Adaptive level of the detail for instructions based on field worker qualification and task.

Function 37: Automatic tracking of work progress.

Function 38: Duration-based abnormality detection.

Function 39: Voice-enabled commands and voice instructions.

Function 40: Remote access of field worker progress to all involved entities.

Function 41: Remote video monitoring capability.

Function 42: Rapid and automated issue report during work execution.

Function 43: Automatic reporting of historical issues of all parts of the work package including steps and equipment, as well as reporting of historical information on how the issues were handled.

Function 44: Ahead-of-time notification of needed support.

Function 45: Real-time update and optimization of the work packages schedule according to current progress.

Function 46: Simplified and integrated feedback or review capability of steps, documents, warnings, plant components, trainings, spare parts, tools, and M&TE.

2.1.10 Sign-Off Clearance and Review

Once the work package main scope has been completed, clearance is signed off and a notification is sent to the supervisor for approval or acknowledgment. AWP will create a summary of the key highlights for the supervisor's evaluation based on the task's progress, issues faced, field worker review, and the task's criticality. Once the supervisor approves the work package, another notification can be sent to operations for their approval, information, or acknowledgment if needed. Once operation approves, the equipment is tagged in, remaining allocated resources are released, and the field worker is tasked with return of M&TE and non-worker assigned tools. This work process automation results in the following AWP function:

Function 47: Automatic identification of key points to report to supervisor for review.

2.1.11 Quality Assurance and Archiving

Worker feedback or review of the steps, documents, warnings, plant components, trainings, spare parts, tools, and M&TE will be sent to a quality assurance system that automatically detects patterns and identifies weaknesses in the work execution process for improvement. Field worker time performance in executing tasks will also be used to modify the needed task execution time and the areas of strength of specific field workers, which would benefit future work assignment. A detailed log of all actions taken by the field worker, along with the resources used, will be archived and sent to quality assurance records. This work process automation results in the following AWP functions:

Function 48: Automatic pattern detection and weaknesses identification in the work package.

Function 49: Automatic development of field workers' areas of strength.

Function 50: Automatic archiving.

2.2 User Needs Survey

The main objectives of the survey are to gain a deeper understanding of what works well in the current work package process and where in the process potential exists for efficiency gain improvements. The participants were asked to consider the whole process from work request to archiving. In addition, participants were encouraged to describe their dream system (i.e., a solution where they did not have to consider limiting factors such as current work processes, technology, regulations, or attitudes).

2.2.1 Development

A web-based format was used for the survey to make it as streamlined and easy as possible to reach out to participants and for participants to complete the survey at a time that worked well for them. The web-link to the survey (shown in Appendix A) was active from April 6, 2016 through May 9, 2016.

The survey contained the following seven questions that were a mix of multiple choice and open-ended questions:

1. Organization (utility and plant) and title/role?
2. Which parts of the work package process work well today (check all that apply)?

3. Please briefly describe what works well in the parts of the process you selected [in Question 2]?
4. Where in the process do you think the greatest efficiency gain can be made (check all that apply)?
5. If you were to make the work package process more efficient, which parts of the process would you automate, remove, change in some way (other than by automation), or keep it as it currently is?
6. Please briefly describe the changes needed to improve the efficiency [for items marked as "Change" in Question 5]?
7. Which of the listed capabilities would help increase the efficiency of the work package process (check all that apply)?

The options used in Question 2 through 6 are based on the work package process description used by the Electric Power Research Institute in EPRI (2015). The process can be described by the following steps or items, all of which were used in the survey:

- Initiation of work request
- Screening work requests
- Planner creates the work package
- Plan and conduct pre-implementation walkdown
- Supervisor selection and assignment of work package to craft
- Validation of craft's qualifications
- Conduct pre-job brief
- Verify the current revision of all documents in the work package
- Walkdown clearance to verify properly hung clearance tag(s)
- Sign-on clearance and update the operations clearance database
- Receive operations' permission to start work
- Sign onto appropriate radiation work request
- Perform work activity
- Sign-off clearance
- Supervisor review
- Work package disassembly
- Filing of quality assurance records
- Archiving.

Researchers identified a set from the advanced functions that has potential to increase efficiency in the work package process. Question 7 asks the participant to identify which of these functions they believe have the greatest impact. The functions description in Question 7 was changed to enable easier out-of-context comprehension of the survey, and to incorporate multiple functions in one bullet when possible for survey optimization. The advanced functions selected by the researchers for the survey are as follows:

- Integration of enterprise asset management system and/or work management system (*Functions 9, 11, 12, 13, and 16)*
- Historical data collection of equipment failures (*Function 4)*

- Automatic population of work package information, including assigned craft, tools, spare parts, equipment, and documents (*Functions 8 and 13)*
- Automatic acquisition of plant information (*Function 9)*
- Automatic scheduling of tasks according to the available resources, priorities, and state of the plant (*Functions 11, 12, 23, and 45)*
- Automatic integration of plant risk information during planning (*Function 6)*
- Automatic tracking of task progress (*Functions 23, 37, and 45)*
- Automatic allocation and release of tools and equipment (*Functions 12, 25, and 27)*
- Pre-recorded pre-job brief videos for frequently performed tasks (*Function 21)*
- Automatic scheduling and guidance of walk-downs and pre-implementation walk-downs (*Functions 11, 14, 15 and 45)*
- Automatic placement and/or removal of hold points (*Function 19)*
- Automatic tracking of craft's location (*Function 28)*
- Automatic notifications to supervisors, operations, and other relevant entities as required (*Functions 32, 33, 42, and 44)*
- Voice-assisted instructions (e.g., talk-to-text) (*Function 39)*
- Remote access of task progress to all involved entities (*Function 40)*
- Remote video monitoring of task execution (*Function 41)*
- Automatic notification to resources for QA and other validations (*Functions 32, 42, 43, and 44)*
- Automatic evaluation of craft's performance (*Functions 18, 37, 38, 40, and 49)*
- Automatic reassignment of tools when not needed (*Functions 12 and 27)*
- Location tracking of tools and spare parts (*Function 24)*
- Automatic tool recall for calibration or disqualification (*Function 25)*
- Augmented reality (e.g., technology similar to Google glasses) (*Functions 17 and 21)*
- Ability to change level of detail in the work instruction based on craft's experience and preference (*Functions 18, 36, and 49).*

The remaining functions that were not directly addressed in Question 7 were surveyed through the automation scope of Question 5 or were deemed trivial for the survey scope by the research team.

2.2.2 Participants

A total of 12 individuals participated in the survey. The participants represented one European and five U.S. commercial nuclear utilities. The participants represent 32% of the total number of plants in the United States. Amongst the participants there were maintenance supervisors, planners, procedure coordinators, and information technology architects.

2.2.3 Data Analysis

Data collected from the survey were analyzed by the researchers. Answers to open-ended questions were both analyzed individually and in an aggregated fashion. Only the aggregated answers will be reflected in this report.

2.2.4 Results and Discussion

The complete survey results are shown in Appendix B. Figure 2 provides a summary of the answers to Question 2, "What works well in the process?" and Question 4, "Where in the process can efficiency gains be made?" As seen in Figure 2, 10 of 12 participants stated that initiating work requests is a part of the current work package process that works well. Participants conclude that initiating work requests works well due to the fact that most utilities have a dedicated system (i.e., most commonly a web-based form) the field workers use to file the work requests.

In addition to initiating work requests, screening of work requests, planner creating a work package, and conducting pre-job briefs were indicated as parts of the process that currently work well. The screening process consists of a group with representatives from all work organizations at the plant who meet routinely throughout the work week to prioritize and schedule work needed to address the work requests. In the current process, the planner uses templates to create work packages, which includes items such as instructions, an equipment list, a material list, documents, clearance requirements, and operations experience. Information used in the pre-job brief is based on Institute of Nuclear Power Operations and utility-specific requirements and is included in the work package. Recently, the nuclear industry started to implement a graded approach to the pre-job briefs, where the level of detail in the pre-job brief is dependent on the task to be conducted.

The red bars in Figure 2 indicate the process areas where efficiency gains are thought to be possible and impactful. The results indicate that performing the work activity is the part of the process where most participants thought efficiency gains can be achieved.

The answers show that disassembling the work package is thought to not work well in the current process. As illustrated in Figure 2, this is also supported by the fact that 38% of the participants identified the work package disassembly as one of the process parts where efficiency gains can be made. The same amount of participants identified filing of quality assurance records and archiving as additional areas where the process can be made more efficient, which is supported by the low score related to how well these parts of the process currently work.

It is interesting to note that creation of the work package, which was identified as a part of the process that currently works well, also is identified as a part where efficiency gains can be made, with 38% of the participants identifying this part of the process as a candidate for efficiency improvement.

Question 5 starts to shift focus from the current work package process to the dream system. The question asked the participants how they would make the system more efficient. The participants were instructed to indicate which parts of the process they would remove, automate, or change in some other way. They were also asked which parts of the process they would like to keep the same way as they currently are.

Figure 3 provides an overview of the results to Question 5. As seen in Figure 3, screening of work requests is only part of the process identified as something that potentially could be removed. However, due to the fact that an overwhelming part of the participants indicated that this part of the process should be kept in its current form, this result is deemed to be inconclusive and requires deeper analysis before any decision to eliminate the screening of work requests is made.

To better understand what can be gleaned from the result, the information in Figure 3 was separated into three different figures: one each for the options automate (Figure 4), change (Figure 5), and keep as is (Figure 6).

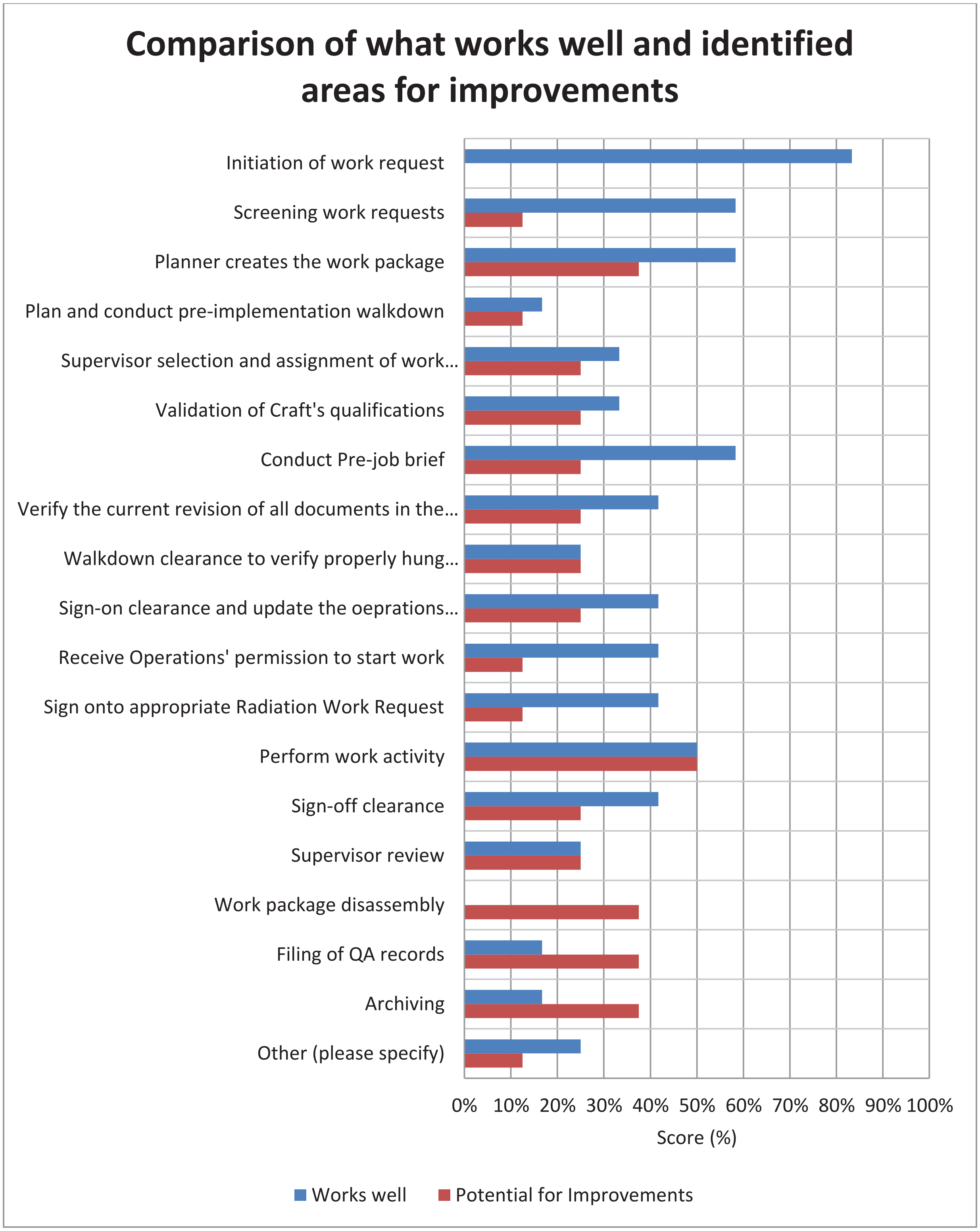

Figure 2. Comparison of what works well in the work package process and identified areas for improvements (Questions 2 and 4).

As seen in both Figure 3 and Figure 4, filing of quality assurance records is a part of the process where automation will be beneficial. This is supported by the fact that only 17% of the participants believe that filing of quality assurance records works well today and 38% identified this as an area for improvements. Figure 6 shows that none of the participants want to leave the quality assurance records process in its current form. The same is true for disassembling the work package, which could potentially be automated (i.e., 71% in Figure 4).

Validating the craft's or field worker qualifications is another area the participants thought could benefit from automation. As illustrated in Figure 4, 86% of the participants indicated that this area should be automated. The participants did not have a clear opinion about if this area works well today or not. However, validation of qualifications is a process that is easy to automate, has potential to be greatly beneficial to the utility in terms of time saved, and mitigates risk of craft or field worker conducting work without the correct/up-to-date qualifications.

As mentioned earlier, archiving was identified as an area that is not very efficient today and has is potential for process improvements. The participants' solution is to automate this part of the process (indicated in Figure 4).

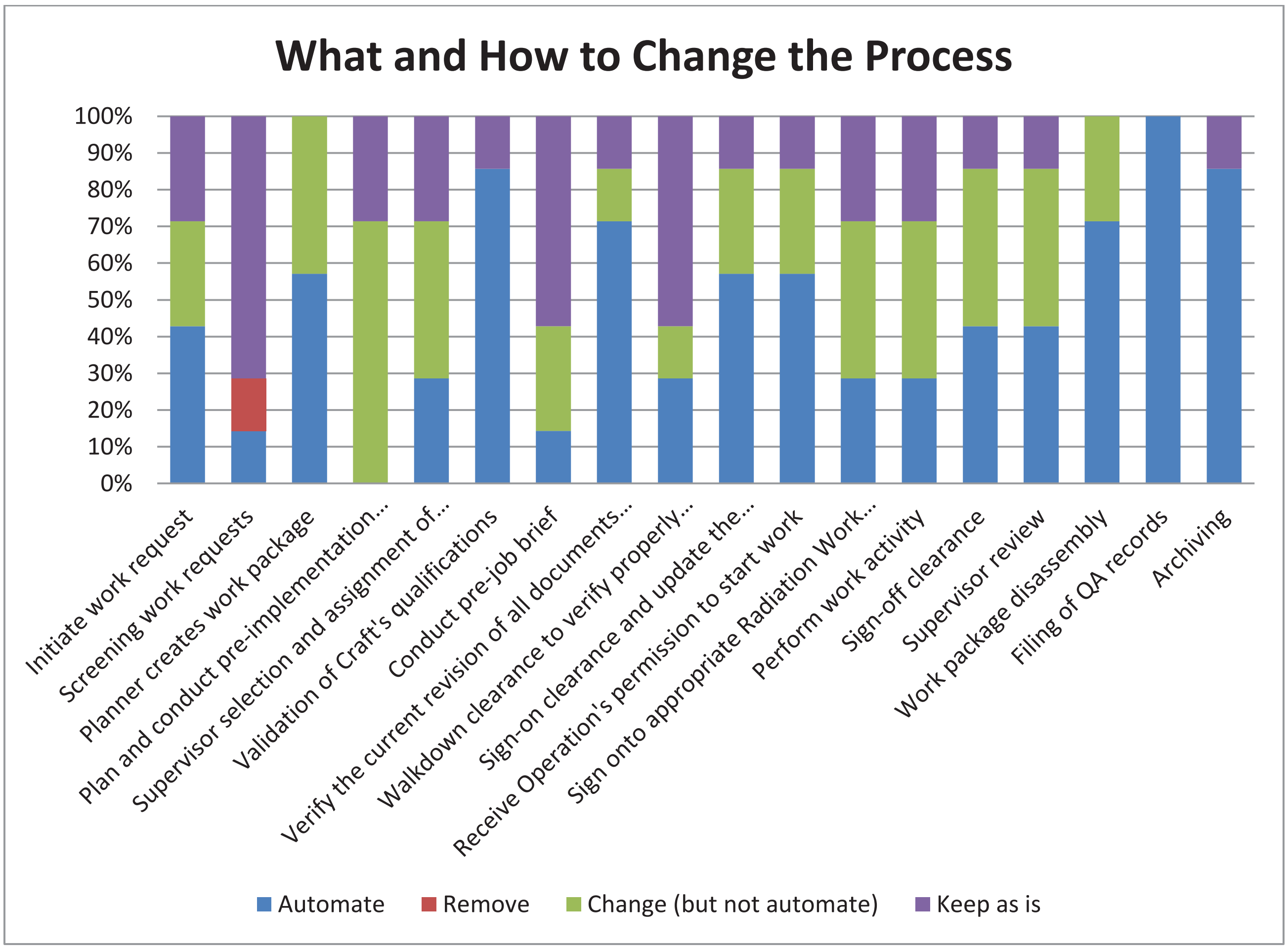

Figure 3. What and how to change the process.

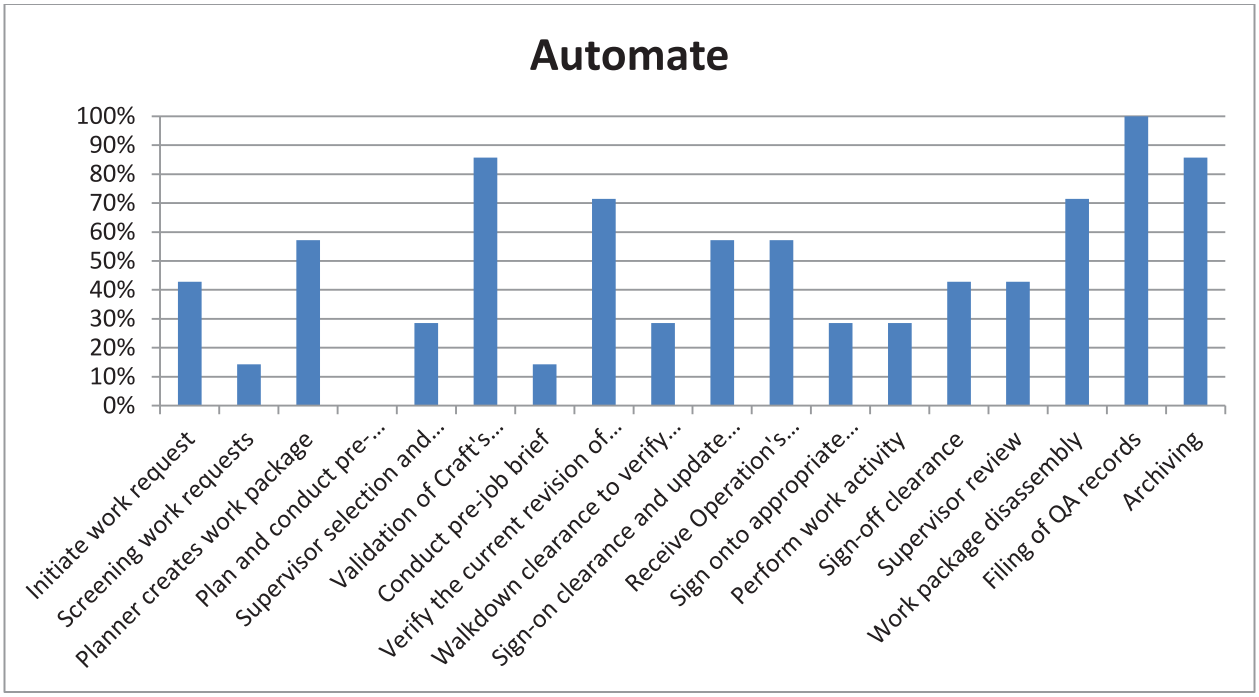

Figure 4. Identified process parts to automate.

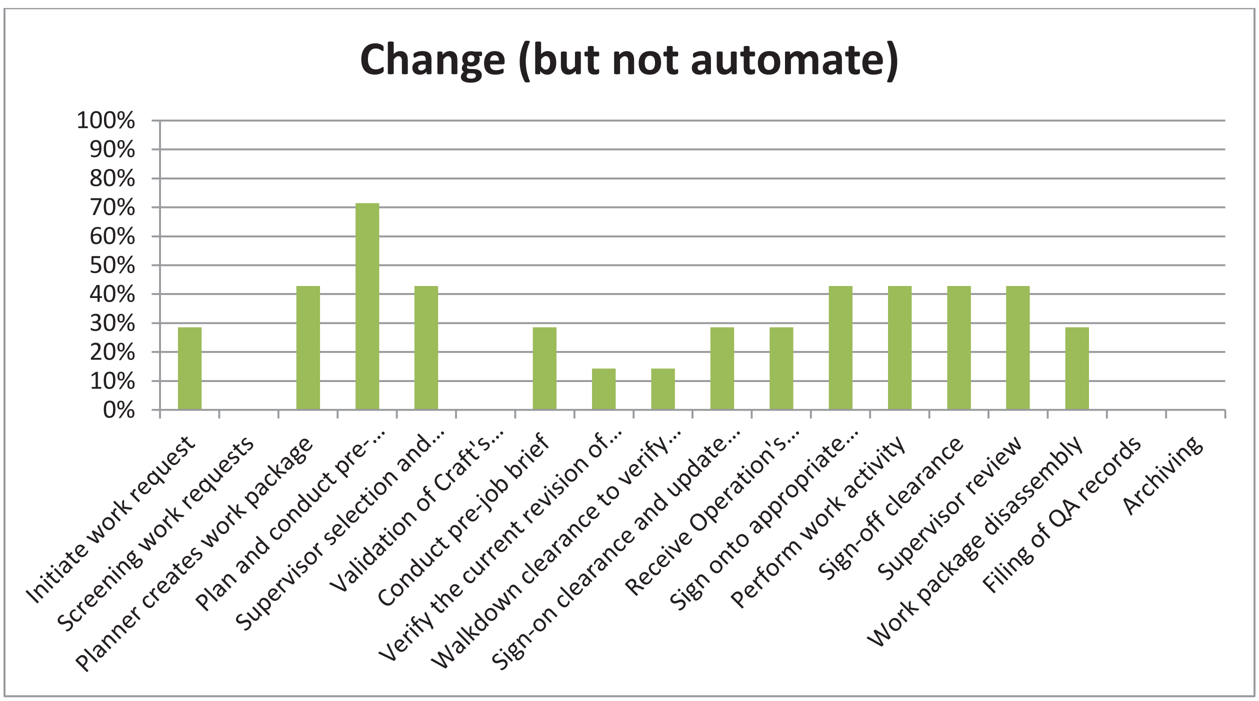

Figure 5. Identified process parts to change but not automate.

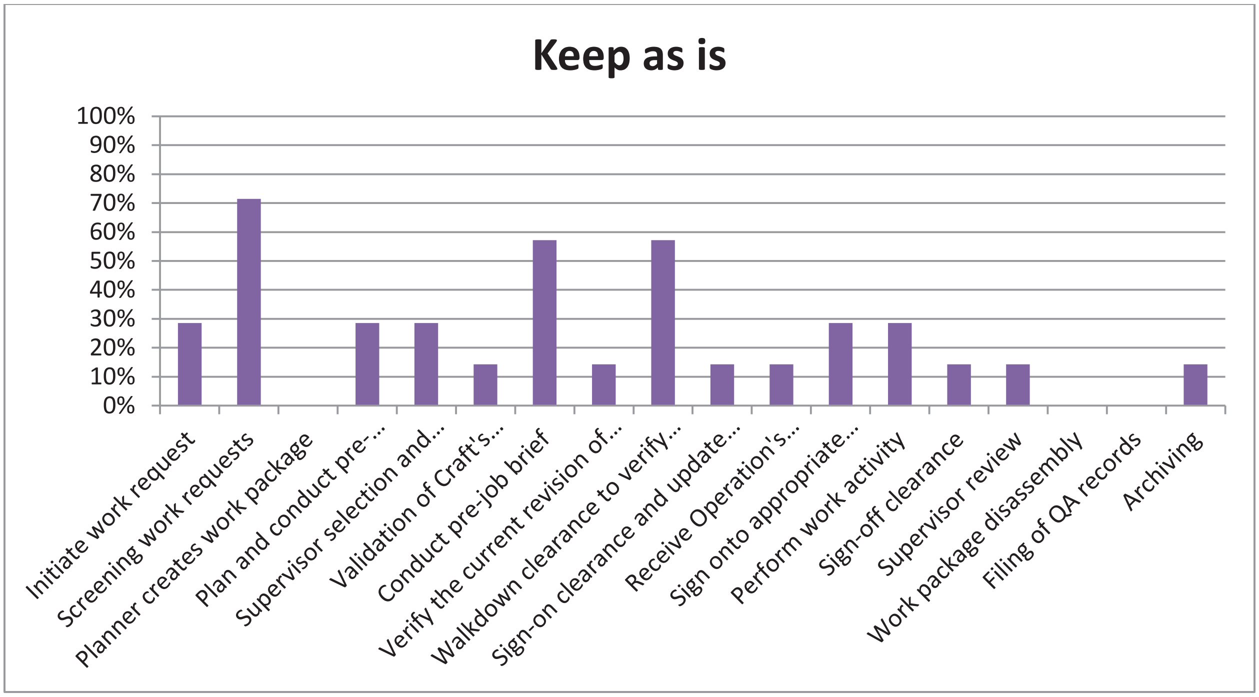

Figure 6. Identified process parts to keep as is.

The part of the work package process related to planning and conducting pre-implementation walk downs was identified as a part that currently does not work very well and where there is room for improvements (illustrated in Figure 2). The participants agree that this part of the process is not suited for automation (0% in Figure 4), but that it is suitable for other types of improvement changes (71% in Figure 5). The free-form replies to Question 6 (i.e., describe the changes needed) point out that the pre-implementation walk down has to be conducted by worker in the field; therefore, it might not be suitable for automation. Suggested changes to the process include a standardization of the process, a more streamlined checklist, and an improved integration of all groups involved in performing the work.

As mentioned earlier, creating work packages is one part of the process that was identified as working well today (i.e., 58% in Figure 2). However, interestingly enough creating work packages was also identified as a part of the process that should not be kept as is (0% in Figure 6). When comparing Figure 4 and Figure 5, it can seem as if the participants are in great disagreement regarding how to improve the process to create work packages; 57% said to use automation and 43% indicated that efficiency gains can be reached without automation. While analyzing the free-form input, the researchers concluded that the most likely scenario is that some parts of the process should be automated, while others are not suited for automation. The planner should still have the main responsibility of creating the actual instruction or work order. However, other parts of the work package can be assembled automatically. Specific data fields in the instruction can also be automatically populated while the planner writes the instruction.

Screening of work requests is a main part of the process that participants would like to keep as is (see Figure 6). This is consistent with the fact that 58% of the participants identified this as a well-functioning part of the process. The participants identified two other categories as something that should be kept in its current form: (1) how the pre-job briefs are conducted and (2) the walk down clearances. If changed at all, it was suggested that the pre-job brief process would be enhanced by smart forms and a more standardized format.

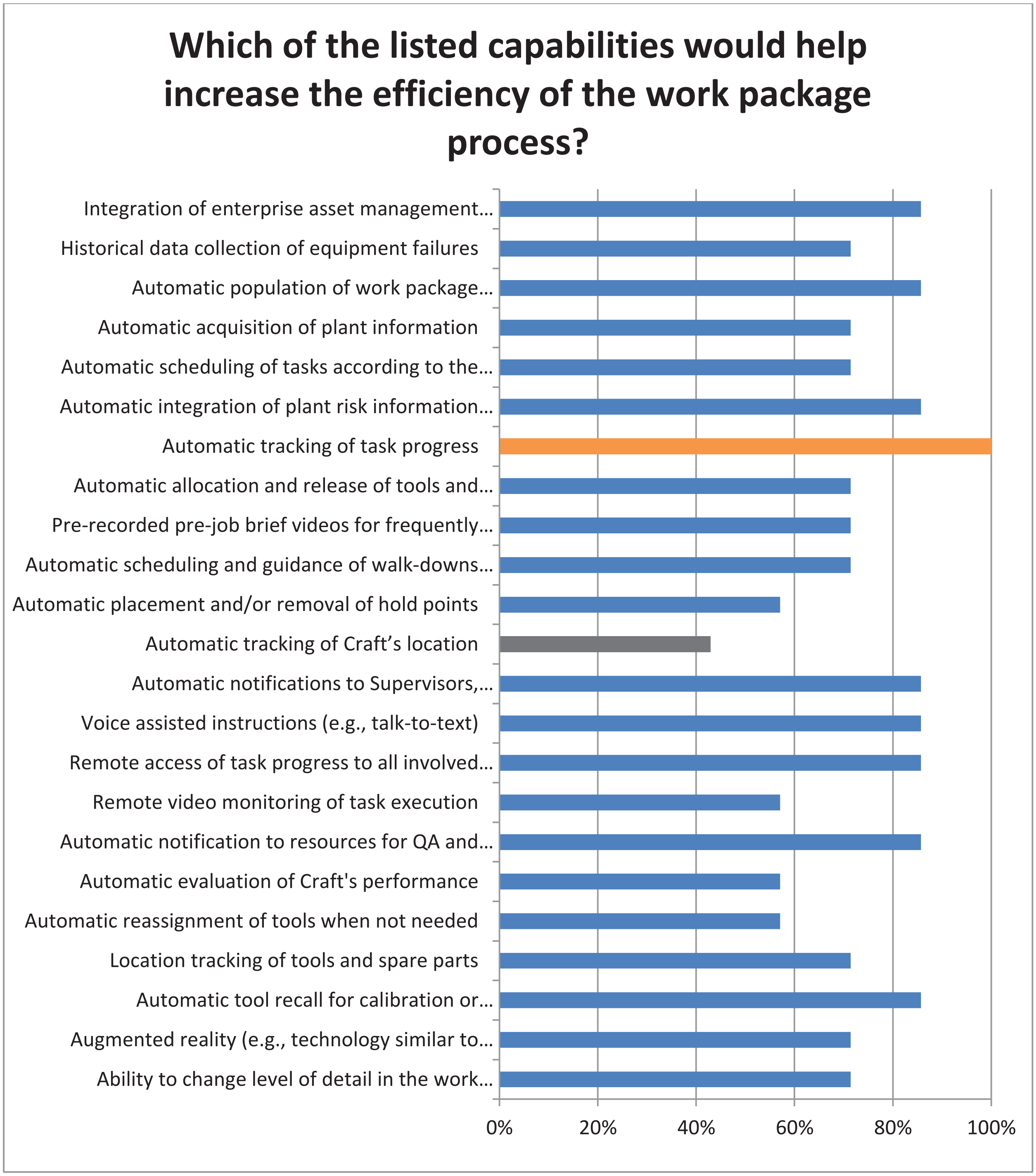

Figure 7. Functions to help increase efficiency in the work package process.

The fact that the majority of the process parts scored low in the "Keep as is" category (Figure 6) can be viewed in two ways: (1) the work package process has great potential for being improved and/or (2) participants are very open to change. Both of these indicate the need to continue the AWP effort for the potential benefits to industry.

The last question in the survey asked the participants to identify capabilities that could help increase the efficiency of the work package process. Researchers provided participants with a pre-defined set of functions, which were presented earlier in this report. As illustrated with an orange bar in Figure 7, the function that all participants identified as useful for increasing efficiency is automatic tracking of task progress. A large portion of the participants (i.e., 86%) identified several other functions as having a great impact on efficiency gains, including the following functions:

1. Integration of enterprise asset management system and/or work management system,
2. Automatic population of work package information including assigned craft, tools, spare-parts, equipment, and documents,
3. Automatic integration of plant risk information during planning,
4. Automatic notifications to supervisors, operations, and other relevant entities as required,
5. Voice assisted instructions (e.g., talk-to-text),
6. Remote access of task progress to all involved entities,
7. Automatic notification to resources for QA and other validations, and
8. Automatic tool recall for calibration or disqualification.

Out of the suggested functions, automatic tracking of the field worker or craft's location was identified as having the least impact on efficiency during the work package process.

3. DATA ARCHITECTURE

Development of an AWP consists of developing the front-end human interface, the back-end data architecture, and the interface between the front-end and back-end. The interface is the framework by which the front-end functions use the back-end data. While the front-end design and development is highly dependent on HF aspects, the back-end and interface design and development are highly dependent on II&C aspects.

In this section, the II&C aspects of the back-end are considered, taking into account the ultimate front-end vision. The aim of this section is to provide high-level principles that are essential to the AWP back-end design and development. These principles are:

1. Hierarchical data architecture
2. Segregation of data based on functionality
3. Replication of templates to instances
4. Incorporation of a logic-based flow of the work package
5. The use of properties and their assignment techniques
6. Flexible integration of the front-end.

The following section explains each of these principles and how they were met in this study. It is necessary at this stage of the report to define some terminologies that will be frequently used in the following sections.

Throughout the report discussion, the expression "table" will be used to describe a data storage array for rows of a certain type. For example, a staff table is a table that contains a row for every staff in the data structure.

Tables can be linked to other tables using one-to-one (OTO), one-to-many (OTM), and many-to-many (MTM) relationships. For example, staff can be assigned one user name and password; this is an OTO relationship. If a device can allow access to multiple users, but users can only access one device;

this is an OTM relationship. If a device allows access to multiple users and a user can access multiple devices; this is an MTM relationship.

A property is any form of resource, information, or action that characterizes the elements of the work package hierarchal architecture introduced in the following section. Properties are associated with the hierarchal architecture through the OTO, OTM, and MTM relationships and will be explained in the following sections.

3.1 Hierarchy

One of the main characteristics of work packages is that they are hierarchical in nature (Figure 8). A work package contains one or more work orders. Each work order contains a set of steps or instructions. The steps are often grouped to achieve a specific scope. The hierarchical architecture can be also visualized by the tree structure of Figure 9.

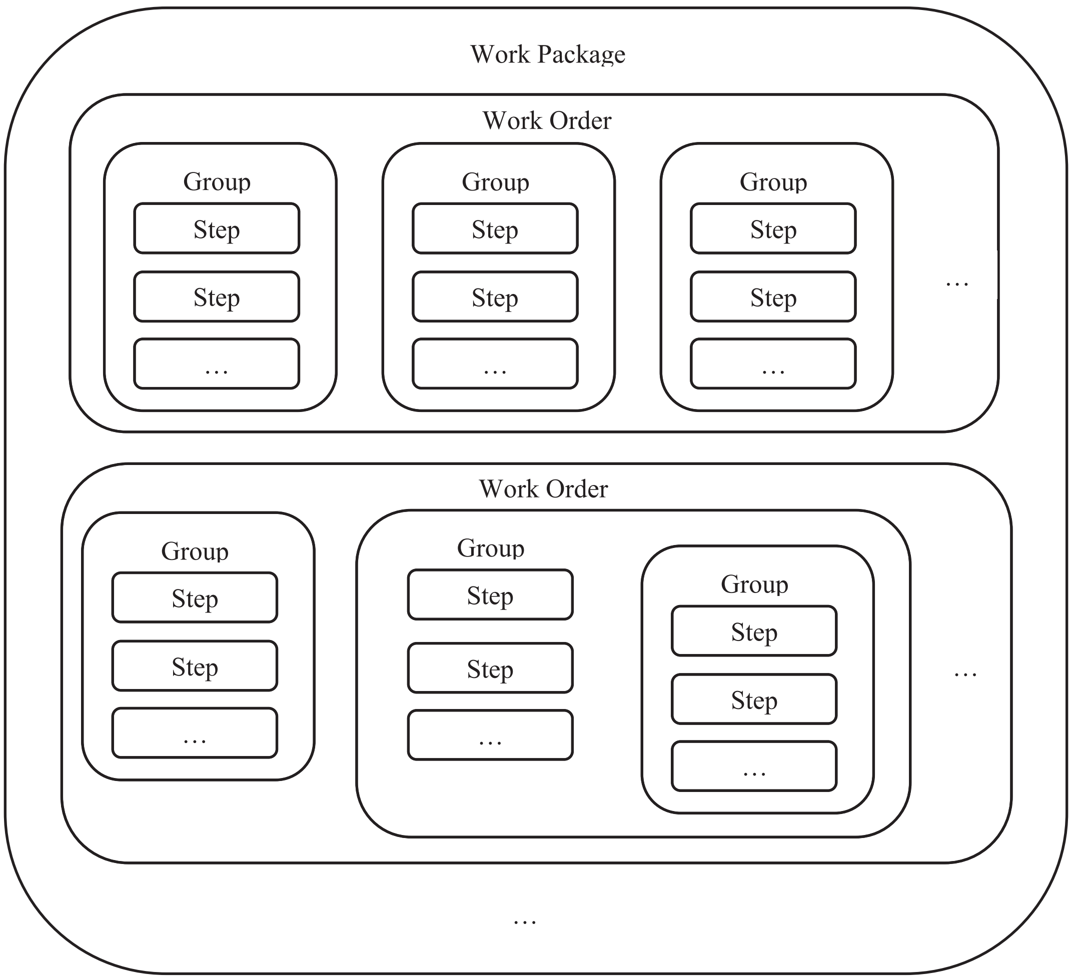

Figure 8. Hierarchical architecture of a work package.

The tree elements in Figure 9 (representing a work package, work order, group, or step in the data architecture) are assigned dedicated tables. The hierarchy was incorporated by an OTM relationship by which one group contains one or more steps, one work order contains one or more groups, and one work package contains one or more work orders. Because a work request can have one work package only, but a work package can be used for multiple work requests, this is another OTM relationship.

In addition to the above-mentioned hierarchical architecture, the current layout of work procedures in the nuclear power industry often encapsulates a group of one or more steps into another group (Figure 8 and Figure 9). To incorporate this, an additional OTM relationship was introduced where one group can contain one or more groups.

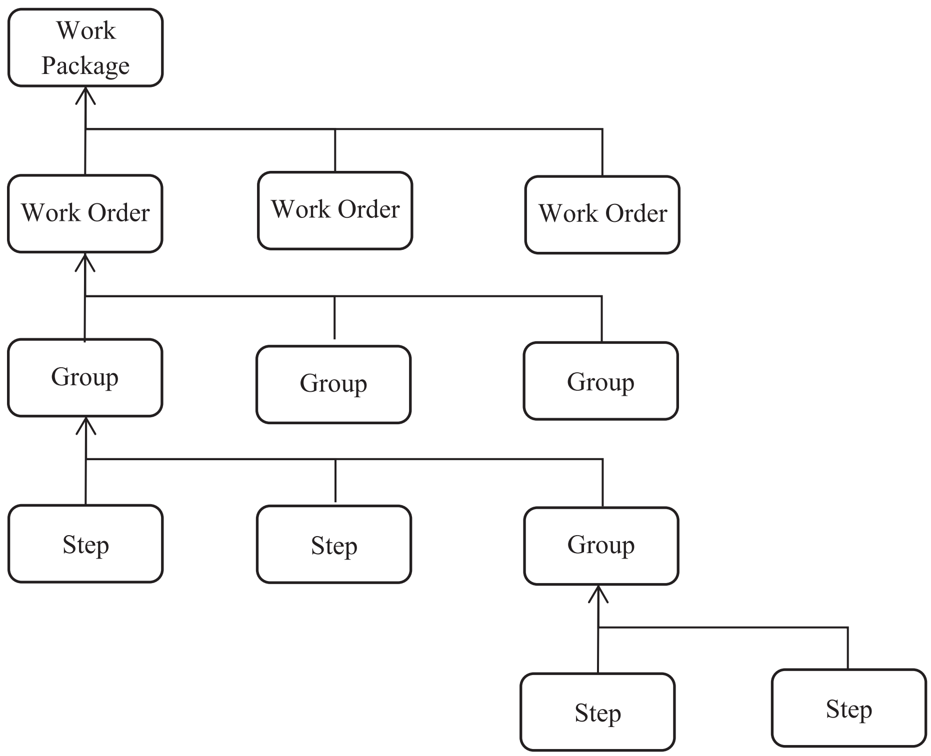

Figure 9. Tree architecture of a work package.

Once the step end of the tree was reached, the data architecture expanded horizontally. A step can be associated with multiple properties. Some of these properties are defined as internal properties and others are external properties. Internal properties are defined in the step table; while external properties are defined in separate tables that are associated through dedicated tables. The decision to define whether a property is internal or external is based on the relationship (i.e. OTO, OTM, or MTM). The OTM and MTM relationships are defined by external properties, while the OTO is ideally integrated into the table. Exceptions do occur for both scenarios. For example, an OTO property can be moved to a separate table for organizational or categorization purposes.

Figure 10 shows some of the external properties defined in this study. Horizontal branching can be defined at the group, work order, or work packages level. For example, groups, work orders, and work packages are linked to review properties to provide feedback on integrated parts of the work package. Some of these properties can span into their own structure, which is demonstrated by the test spanning into its own tree in Figure 10. In other instances, the properties are directly associated with each other (such as the hazard and document association in in Figure 10).

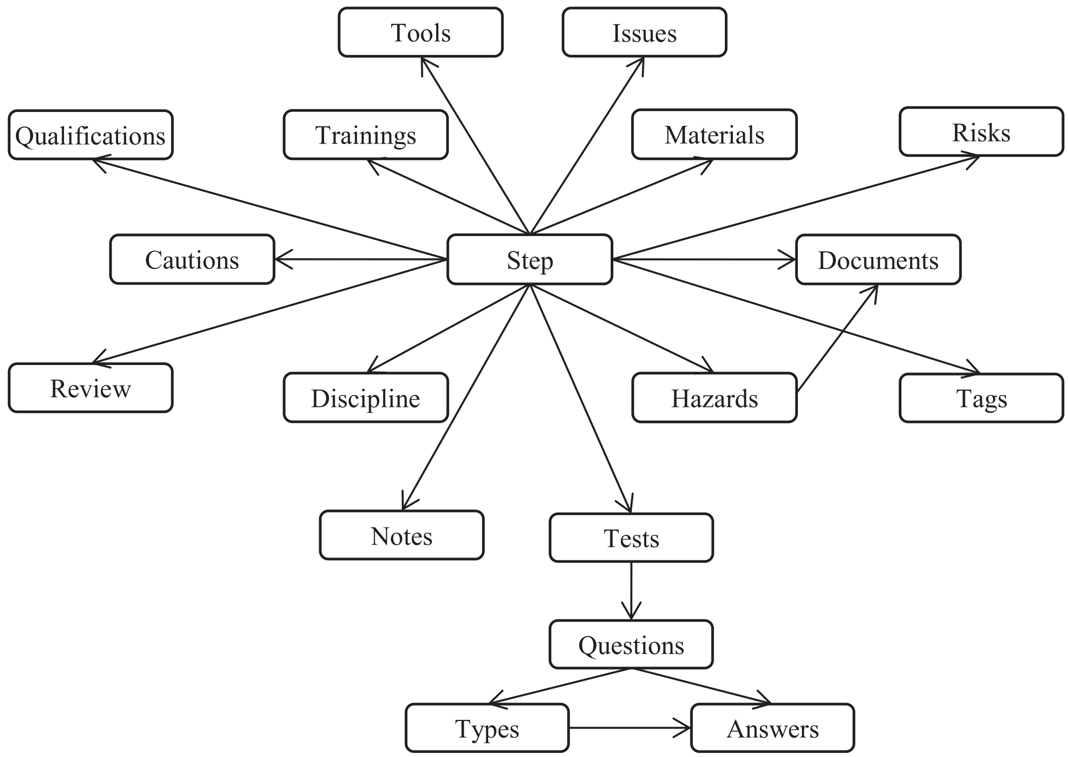

Figure 10. Structure of step external properties.

3.2 Functionality

From an organizational and security perspective, it is recommended to segregate the data, based on its functionality. In AWPs, this implies that the tables used by planners are different than those used by the scheduler and field workers.

The planner's data are placed in configuration tables, because they define data that are specific to work package development, assembly, and configuration. The schedulers and field workers data are placed in live tables because they reflect the live status of data.

The AWP segregation functionality principle is illustrated in the example of Figure 11. Figure 11 shows that at every level of the hierarchy of the previous section, a configuration and live version exist. A typical configuration step, for example, contains properties that are fixed (such as the step name, description, and revision). A typical live step contains properties such as status, start time stamp, end time stamp. A detailed example list of properties for each table of the tree elements is listed in Appendix C.

Introduction of configuration and live tables resulted in seven different scenarios categorized into three association categories:

1. Configuration-to-configuration data association: In this category the configuration state of data is linked to the configuration state of other data. This includes the following three scenarios:
    a. Tree element connected to a property: Figure 11 shows an example of where a planner associates a step configuration data with a tag configuration data. The actual status of the tag is in the live state.
    b. Tree element connected to another tree element: Figure 11 shows an example where a planner associates the work package configuration data with work order configuration data.

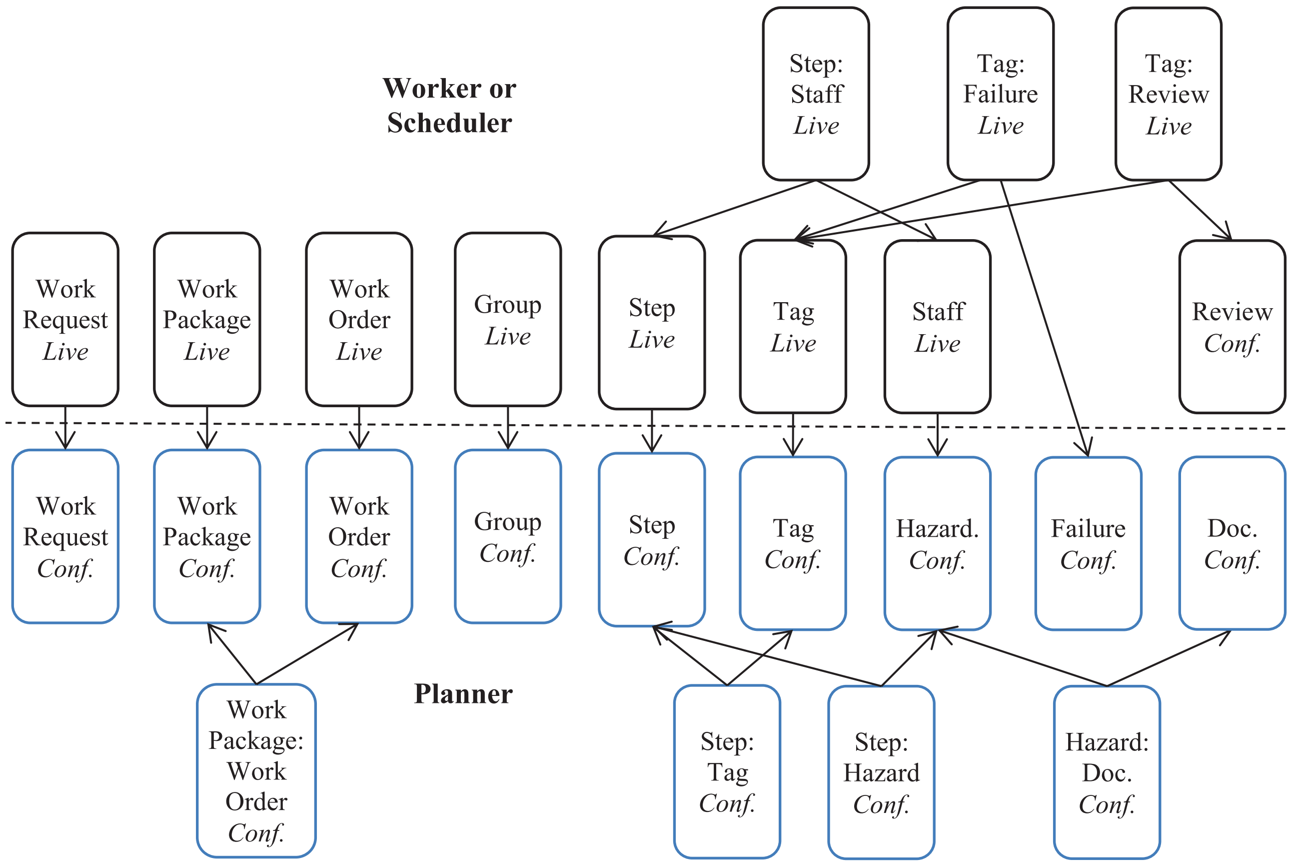

Figure 11. Example live and configuration data association.

   c. Property connected to a property: Figure 11 shows an example where a planner associates the hazard configuration data with the document configuration data.

2. Live-to-live data association: In this category, the live state of data is linked to the live state of other data. This includes the following two scenarios:
   - Tree element connected to a property: Figure 11 shows an example where the scheduler associates step live data with a staff live data.
   - Property connected to a property: Figure 11 shows an example where a field worker associates the tag live data with review live data.
3. Live-to-configuration data association: In this category the live state of the data is linked to the configuration state of other data. This includes the following two scenarios:
   - Tree element connected to another tree element: Figure 11 shows an example where the scheduler associates a work package live data with a work package configuration data.
   - Property connected to a property: Figure 11 shows an example where the field worker associates a tag live data with a failure configuration data.

The above configuration-to-configuration association is a OTO, OTM, or MTM relationship. The live-to-live link is also an OTO, OTM, or MTM. For example a tag live data can have multiple review live data, but a live review data can be associated with one tag live data (OTM), and a live step data can have multiple live staff data, while a live staff data can be assigned to multiple live steps data (MTM).

The live to configuration association is an OTM relationship, because one live data element can be linked to one configuration data, but a configuration data can be linked to multiple live data.

3.3 Replication

The replication of templates to instances was deemed as another key principle of the data architecture. A template is a repeatedly used layout and data. The instance of the template is a child object that will acquire a copy of the template layout and data. Some of the acquired template information can be changed at the instance level, while others can only be changed at the template level.

To achieve this requirement, the data architecture adopted the object-oriented programming architecture. This resulted in two types of tables in the data structure: template (or class) and instance tables. To understand the need for such architecture, it is necessary to describe the process in the context of a planner.

If the planner is defining a step, the planner is actually creating a template. During the template definition, the planner will define properties that are constant in the step (such as its name, description, tag, materials, and documents) and others that are non-constant (i.e., variable) properties (such as the issue probability and execution time). As soon as a step is inserted into a group, an instance is created and the instance is associated with the group. The planner can edit the variable properties of the step in the group and these changes will only affect that instance. If the step constants (name for example) need to be changed, the planner has to access the template and modify it. This will cascade the change to all the step instances in all groups. This broad impact results in the desire to reduce the number of constants in the template definition; however, this is actually a storage versus flexibility compromise. The high number of variable properties in a template results in a large instance storage size, but more flexible instance configuration.

Figure 12 demonstrates, in a simplified approach, how the concept of template and instance can be applied to groups and work orders. The same principle applies to all levels of the work package tree. In Figure 12, every time a new table is created, the number in the database table (DBT) symbol is incremented. According Figure 12, the steps to create a work package are defined as follows:

1. A step template is defined and its internal parameters are defined. The step internal properties are defined in the step table (DBT 1)
2. The step template is associated with an external property template (DBT 2). External properties are defined in separate tables and associated explicitly with the step (DBT 3). Figure 10 shows some of these properties.
3. A group template and its internal parameters are defined. The group internal properties are defined in the group table (DBT 4).
4. A step instance is created (DBT 5). The instance replicates the template constant and variable properties. The external properties are not instantiated, but the link to the properties is instantiated (DBT 6) to enable the step instance to modify the link to external property templates.
5. The step instance is associated with the group template (DBT 7).
6. A group instance is created (DBT 8). The instance replicates the template constant and variable properties.
7. If the group is recursively associating another group, an association is created (DBT 9).
8. A work order template is defined and its internal parameters are defined. The work order internal properties are defined in the work order table (DBT 10).

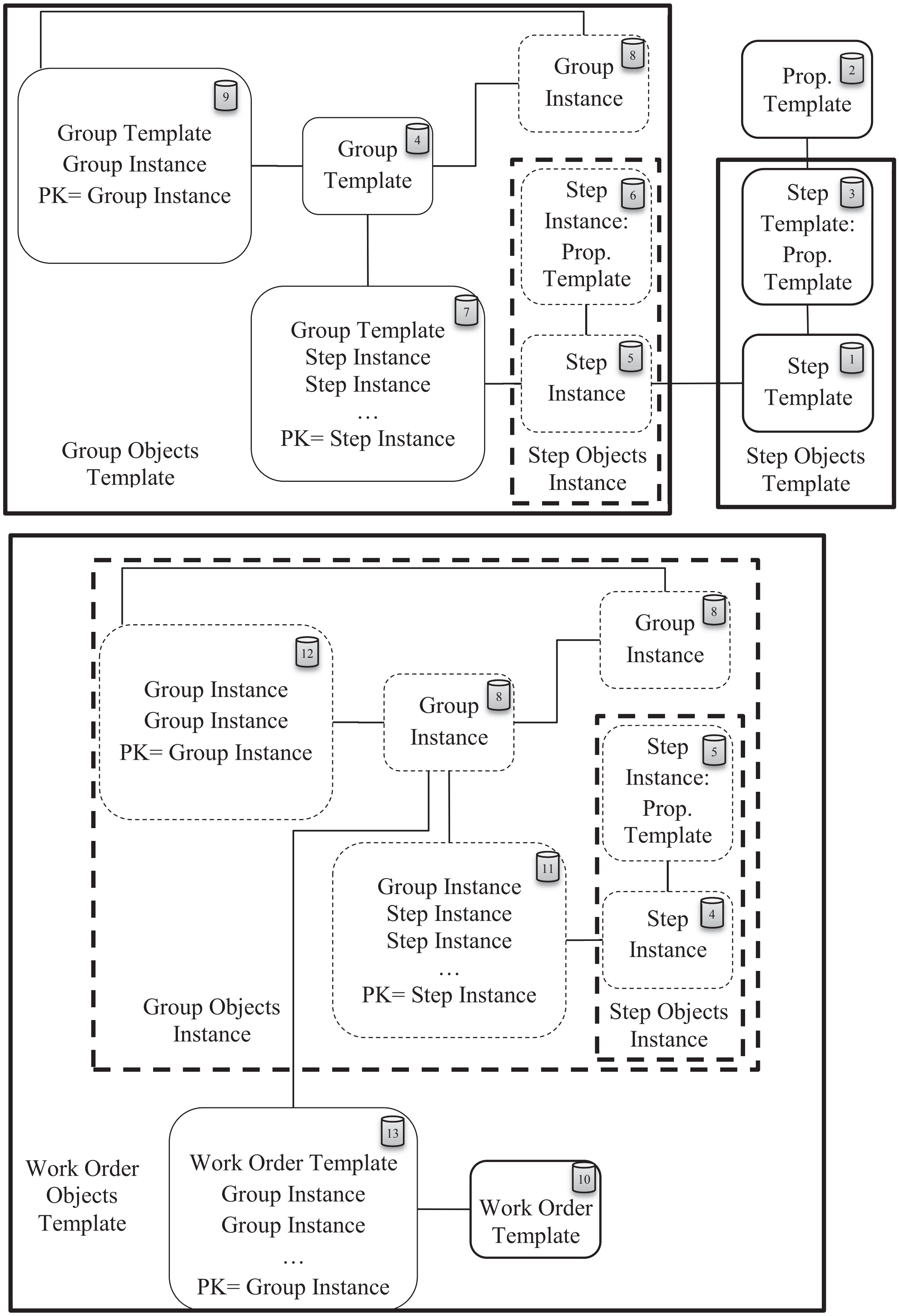

Figure 12. Replication of template and instance data.

9. All group objects defined earlier are instantiated by creating an instance version of all template data (DBT 11 and 12).
10. The group instance is associated with the work order template (DBT 13).

Though not shown in Figure 12, it is also possible for groups and work orders to have external parameters that also result in an association templates and instances. For example, just like a step can be associated with a tag representing a specific component, a group or work orders can be associated with a tag representing the larger component that the step components is part of.

3.4 Steps Flow

The association of steps to groups, groups to work orders, or work orders to work packages does not describe the flow of work package steps. To enable this, the planner needs to define links between the steps in a group, work order, or work package level. These links can directly sequence two steps or they can include logical statements to decide on the step to perform next. The three developed logic operators in this study were an "and" or "or" and negate operators. An example in which an "or" operator is needed is shown in Figure 13. In this example, Step 2 is to be executed if Step 1 is completed with a true condition of a test. Step 3 will be executed by either completion of Step 2 or by failure of the Step 1 test.

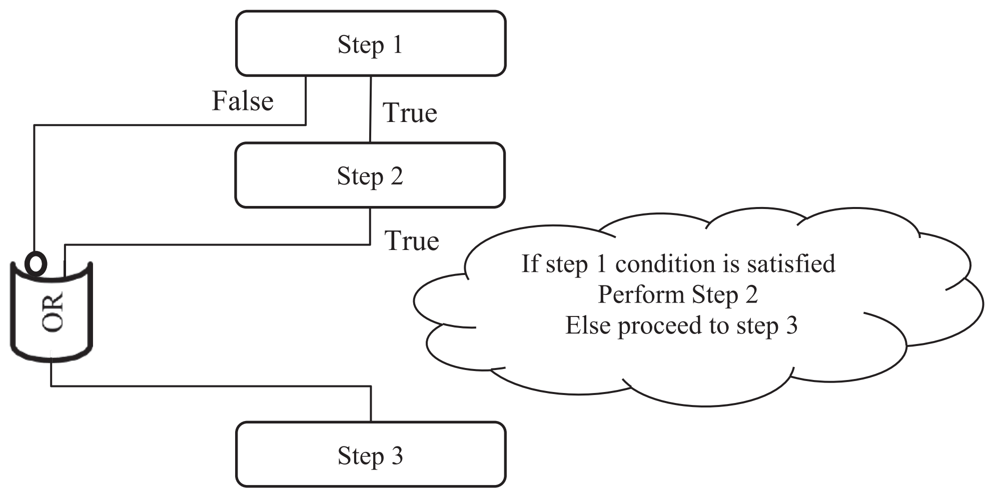

Figure 13. Example logic flow of steps.

To enable logic implementation in the data architecture, tables representing the links between the steps and logic operators need to be defined. Therefore, it is not required to link groups, work order, or work packages, but the steps they include. The linkage process is limited by the level of configuration. This implies that it is logical to link steps in a group to other steps in the group. If a step in a group is to be linked to a step in another group, the links need to be added in the work order level of configuration. If the steps in a work order are to be linked to a step in another work order, the link is defined on the work package level of configuration. The link definition can only apply to step instances (i.e. not templates). If a step instance is linked to another step instance in a group template, instancing the group would create a copy of the link.

3.5 Properties

The previous subsections introduced the two types of properties: internal and external. In this subsection, the properties definitions and associations are further explained. It was necessary to ask the following questions for each property in the AWP data architecture:

1. Where would be the optimal level for associating the property in terms of the following:

a. Speed of use for the planner?
b. Storage impact?
c. Function?

2. Is the property associated with other properties in addition to the tree elements?
3. What is the nature of the association to tree elements and other properties (OTO, OTM, or MTM)?
4. Who will access the property? and Is there a need to assign the property into configuration and/or live data states?

To address Question 1.a, it was decided that steps are the most common replicated part of the work package. Therefore, it was decided to associate the majority of properties to steps. However, this does not require the planner to associate all properties with a step. If the planner does not associate a certain property with a step, no new entry is added to the step-property association table.

Once a step has been added to a group, the step properties are cascaded to the group, even though they are not explicitly assigned to the group. For example, the priority of a group can be defined as the highest priority of a step in that group. Once a work package's compilation is complete, the properties of all steps become the work package properties. There is thus no need to specifically define materials, tools, M&TE, hazards, risks, or documents by the planner. They are cascaded from the steps upward.

To address Question 1.b, it was decided that an MTM relationship would be used between the tree elements and most of the properties. This implies that a dedicated table for associating a step with a property is defined. If no element is added to the table, no association is created and no data storage is needed. It was also decided to associate the majority of the properties as templates. Therefore, they are not replicated when a step instance is created. Only their link to the step instance is replicated. Any property that exists in the instance table is a property that the planner can edit. A property that is not replicated is only editable in the template version.

The majority of the functions of the AWP were evaluated against all the levels of the tree elements as was required by Question 1.c. The internal properties were added for all levels, while the majority of the external properties were step properties. The tables association can be found in Appendix C.

The property-to-property relationship of Question 2 was found to be needed often. The major motive behind this need was either to enable further hierarchy development beyond the step level (as was indicated in the test property of Figure 10), or was based on an attempt to introduce further automation into procedure writing. An example of the latter part is associating a hazard with a document or training to spare the planner from having to manually associate these properties to the step.

Question 3 require defining whether the property will need to be associated multiple times to a tree element or another property and whether the tree element or another property will be associated multiple times with this property.

Question 4 defines whether the property will have a configuration state, a live state, or both. This depends on the type of information that will go into the property; specifically who is the property user or when would the property data change.

3.6 Front-End Interface

The interface to the front-end is another principle of data architecture. This is directly correlated to the flow chart of creating the work package shown in Figure 14 and executing the work package shown in Figure 15.

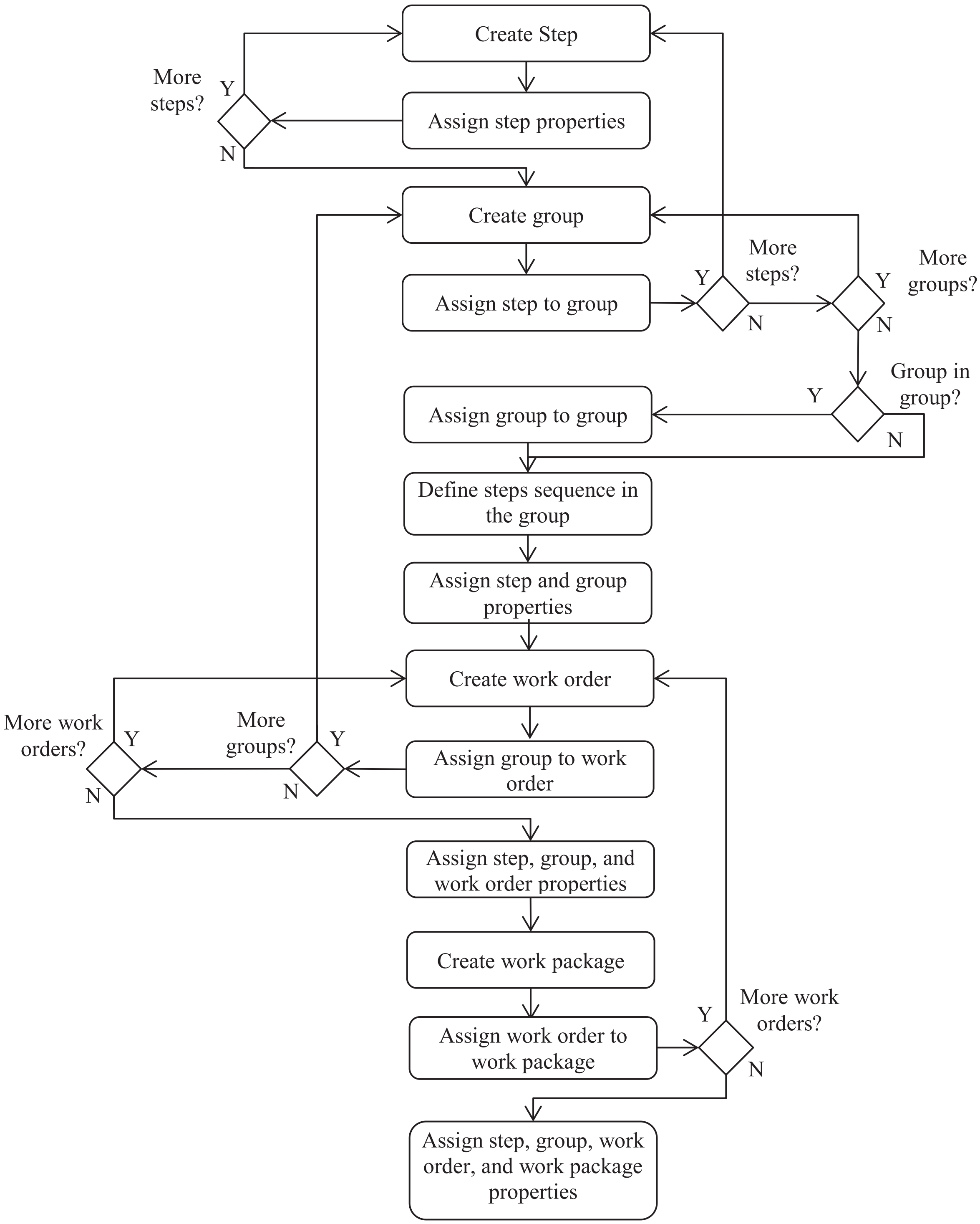

Figure 14. Flow chart of work package creation.

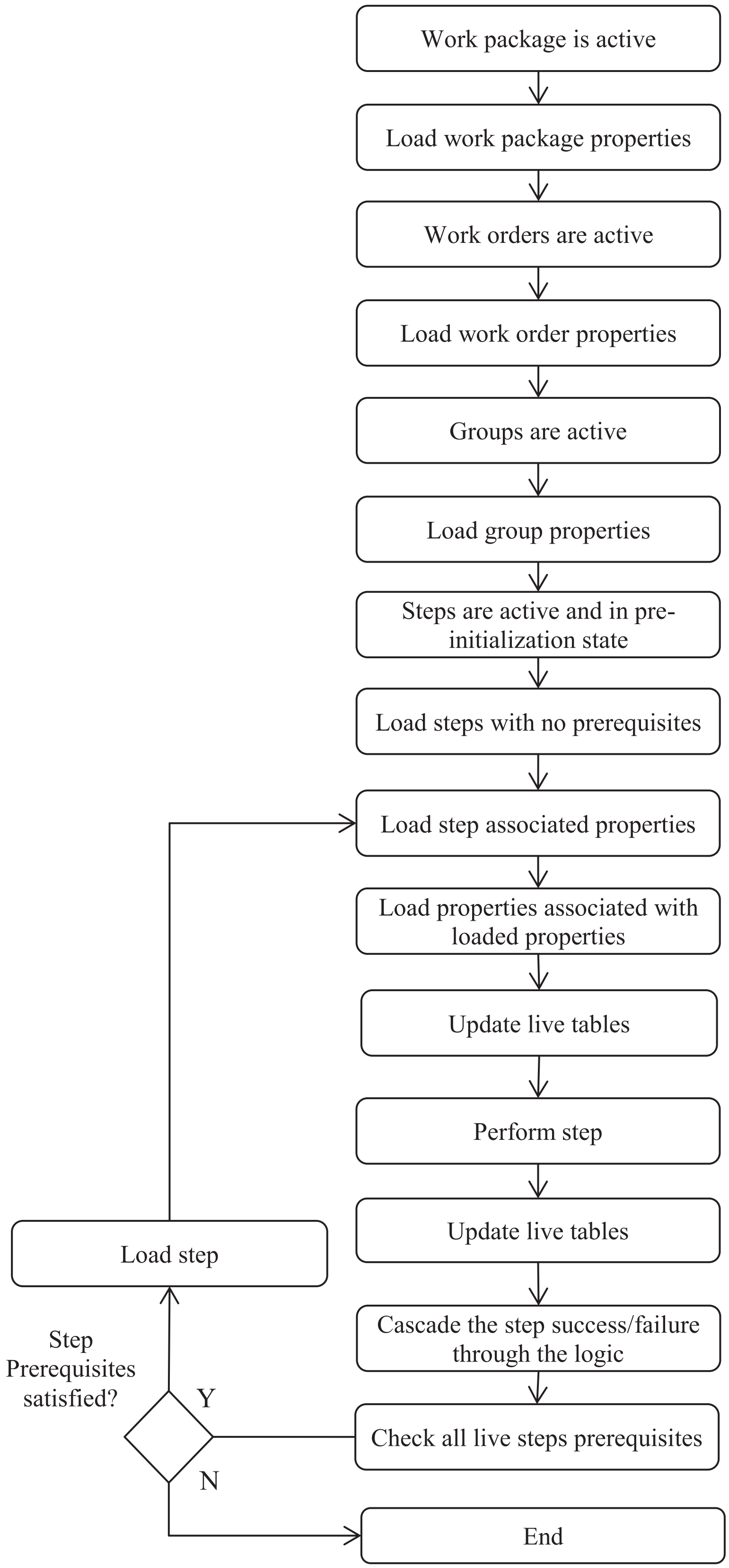

Figure 15. Flow chart of work package execution.

The work package creation process is envisioned as a bottom to top tree development process, where the bottom is the step and the top is the work package. The procedure defines steps, assigns their properties, and then places the steps into groups. The steps are then linked. The properties of the steps and groups are then changed as needed. The groups, along with their steps, are placed in work orders. The work order steps are linked. The properties of the steps, groups, and work orders are changed as needed. The work orders are then placed in work packages. The work package steps are linked. The properties of the steps, groups, work orders, and work package are then changed as needed. This process is explained in the context of Figure 14 as follows:

- Creating a step: An entry is added to the step template table. The front-end graphical object of the step is associated with a unique key identifier to the table entry. If the step is created by copying another step, an instance of the already existent template or instance is created. The variable properties' links are cascaded to the new instance. A link between the new instance and the template is established for the instance to associate to the constant template properties.
- Assigning a step property: A new entry is added to the step property association table if the property is an external property. If the property is an internal property, the step property field is updated with the property value. If the property entry is of a new property that does not exist in the property template table, a new entry is created in the property template table. If the property is associated with other properties, a new entry is created in the property-property association table.
- Creating a group: An entry is added to the group template table. The front-end graphical object of the group is associated with a unique key identifier to the table entry. If the group is created by copying another group, an instance of the already existent template or instance is created. The variable properties' links are cascaded to the new instance. A link between the new instance and the template is established for the instance to associate to the constant template properties.
- Assigning a step to a group: An instance of the step template or instance is created as was described in "Creating a step", and the instance is linked to the group by creating a group-step association.
- Assigning a group to a group: An instance of the group template is created as described in "Creating a group", and the instance is linked to the group template by creating a group-group association. The rest of the Figure 14 processes follow a similar approach as mentioned above.

Once a work package is executed, the work package loads all instances of work orders, groups, and steps. The instances are reflected in the live tables. The tree element association tables with external properties are queried. If the property association query does not return any results, it means the tree elements are not associated with that property. If a tree element is associated with multiple properties, the query would return all of them.

Once a property is determined to be associated with a tree element, the property association with other properties is also queried. This process occurs till the complete property chains of association have been revealed. For example, if a step is associated with a hazard property, the hazard association with documents is checked next. If the association exists, the document's association with other properties is checked, and so on.

To start a live step, the prerequisites of the step have to be satisfied. The step prerequisites can be a set of logical gates or multiple steps as was explained in Section 3.4. The prerequisites table links the step to an "and" gate, "or" gate, or a step. These objects are linked to other gates or steps in a chain of logical gates and steps. The front-end interface will perform the logical operation, generate the results, and then execute the next live step that has satisfied prerequisites. This process is explained in the context of Figure 15 as follow:

- Work package is active: An entry is added to the work package live table. The front-end work package graphical object is associated with a unique key identifier to this entry. The layout of the graphical object is loaded from the work package template.
- Load work package property: A new entry is added to the work package-property live table if it is an external property. If it is an internal property, the property field is updated with the property value. If the property is associated with other properties, a new entry is created in the property-property live association table.
- Work order is active: The work package's work order instance is loaded into the front-end. An entry is added to the work order live table. The front-end work order graphical object is associated with a unique key identifier to this entry. The layout of the graphical object is loaded from the work order template.
- Load work order property, group is in live state, load group property: Follow a similar approach as the explained in the work package initiation process; not listed for brevity.
- Step is active and in the pre-initialization state: A new entry is added to the step live table. The step graphical object is associated with a unique key identifier to this entry.
- Load steps with no prerequisites: The step that has NULL as its pre-requisites is loaded. This step is one of the seeds of the work package parallel flow execution.
- Load step-associated property: Follows a similar approach as mentioned in the work package initiation process; not listed for brevity.
- Update live tables: Before the step is executed, live properties (such as the start time stamp) are updated. After the step is completed, other live properties such as end time stamp are updated. The update process affects all the tree elements and the associated properties.
- Perform step: The state of the step is changed from pre-initialization to in progress.
- Cascade the step success/failure through the flow logic: The completed steps (with success or failure) are reflected into a binary one or zero state that is then cascaded through the logical gates. The step prerequisites are then updated for all live steps.
- Check all live step prerequisites: The steps prerequisites are checked to determine if the cascading process of the previous process caused any step prerequisites to be satisfied. The steps with satisfied pre-requisites are executed next.
- The process is repeated till no step has a satisfied prerequisite. This indicates reaching the end of the work package or the end of one of its execution paths.

3.7 Principles Coupling

A demonstrative example of coupling the data architecture principles of the previous sections is shown in Appendix C Table 1 to Table 5. The tree elements, in addition to the work request, are split into template configuration, instance configuration, and instance live. Template tables do not have live versions. This is logical because a template cannot be used in a work package, but its instance is used instead.

A tree element instance configuration table must always have a link to the template configuration table and an instance live table must always have a link to the instance configuration table; therefore the instance live table is indirectly linked to the template configuration table.

Table 6 in Appendix C lists the external properties that are used to link a step to another step or logical gates. The connection of the logical gates to other steps is defined through dedicated link tables.

For example, if an "and" gate operates on a step and an "or" gate, an entry is added to an "and:step-link" configuration table, and another to an "and:or-link" configuration table.

Each of the mentioned three categories (template configuration, instance configuration, and instance live) has its own internal and external properties (Table 1 to Table 5 in Appendix C). The properties definition and association are developer dependent. The shown definitions and associations in Appendix C are intended for demonstration only. The properties details of association with other properties are not presented in this report since they are developer dependent.

The principles coupling resulted in a data architecture that can incorporate the functions introduced in section 2. The details of the back-end implementation of each function will be included in future efforts when the front-end and interface framework are developed for that function. A few examples are presented for illustration:

Example 1: The frequency, cyclic flag, initiator type, initiator staff, and initiation time stamp properties of the work request template configuration in Table 5 are intended to enable the automatic creation of work request (*Function* 1), the coupling of work requests to plant equipment that perform self-diagnosis and prognosis (*Function* 2), and intelligent plant discrepancies identification systems (*Function* 3).

Example 2: The latitude, longitude, and altitude properties of material and tool item live tables shown in Table 7 and Table 8 of Appendix D are intended to enable RFID tracking of M&TE, tools, and spare parts (*Function* 24).

Example 3: The association of a step template or instance configuration with disciplines, which identifies the type of response required by the discipline from: action, acknowledgment, notification, clearance and/or closure in Table 9 of Appendix D is intended to enable automatic notification and clearance to supervisors, operations, and other relevant organizations (*Function*s 32, 33, and 44). The live aspect of this capability is incorporated using the associations of the step instance live table with discipline live properties representing the time stamp of the occurrence for each of the configured responses (Table 10 in Appendix D).

4. SAMPLE IMPLEMENTATION

To evaluate the developed data architecture, it was applied to an example work order from a utility. This resulted in several iterations to best fit the work order into the data architecture. This section describes the work order and the work order improvements that resulted from this effort.

4.1 Work Order Description

The work order that was used was meant to perform cyclic maintenance on the lube oil tank of the main feed water turbine. The work order's details are described in a generic manner in this report to protect the proprietorial information of the work order's owner. The work order had the standard utility cover page, impacted plant equipment list, materials list, documents list, walk down checklist, instructions, risk and impact forms, hazards and safety forms, and quality assurance forms. The work order contained more than 25 pages and more than 100 instructions or entry questions. The main initial observations were:

(1) The amount of information displayed in some pages was tremendous.

(2) Not all the materials and documents listed were referenced in the instructions.

(3) The instruction's complexity was variant.

(4) The forms order does not follow the general work process flow.

(5) The properties defined in the earlier sections were mainly associated with the work order level rather than the step level.

(6) The hazards and risks of the work order were not clearly associated with specific instructions.

4.2 Work Order Improvements and Benefits

Incorporation of the work order into the data architecture revealed several work order improvements. This section will describe these improvements.

The current approach of work order information development relies on evaluating the work order as a whole. Properties such as impact, criticality, risks, and hazards are often associated with the work order, not the steps. The implementation of the data architecture forced the association of the majority of the work order properties to steps. The properties association to steps resulted in several benefits as discussed below.

The properties association to steps resulted in better field worker use of properties. The field worker needs to know about the majority of the step properties just before the relevant step is executed, in addition to viewing the overall work order properties at the beginning of the work order execution.

The properties association to steps simplified development of work packages for planners. Instead of defining on the overall properties of a work order, the planner just adds steps that already have defined properties to the work order. These steps will automatically cascade their properties to the work order.

The properties representing resources such as documents, M&TE, tools, and materials do not need to be manually inserted anymore because they are automatically pulled from the data tables when a step is included in the work order. This resulted in preventing missing needed resources, acquiring unneeded resources, and using wrong resources.

Association of properties to steps eliminated a large portion of information that is presented in the cover page. It also eliminated the risk and hazards evaluation forms, the operations impact evaluation forms, and the impacted components list. These forms were replaced by step properties that, along with the disciplines of importance, can automatically perform the evaluation.

Instead of a fixed field worker performing the work order, the data architecture allowed dynamic step level tasking and resource reallocation, which is not possible in the current work order design. The current work order relies on the clock in and clock out approach, without direct association with the step. In addition, work progress time stamping was not possible in the current design. Implementation of the data architecture facilitated this function.

The call for assistance from other plant organizations was eliminated and replaced by associating a discipline to a step. This automatically integrates the steps from multiple organizations.

The manual request for M&TE, tools, and materials was eliminated from the work order, because it is automated in AWP to occur soon before the scheduled work package is about to start. The manual tracking of M&TE was also eliminated, because it is also automated in AWP.

Information presented in the work order was not categorized into nature of use. For example, safety-relevant information was presented in the same area as scheduling information. This was segregated in the data architecture because the majority of safety information is planner data, while the scheduling information is scheduler data.

The level of step details was found to be inconsistent. Some steps were found to include multiple steps in their description. These steps were forced to break down in the data tables. Some steps contained too many properties for a single step. These steps were also broken down. The logic flow of the steps was not always clear. Implementation of the data architecture resulted in a better flow of the steps. In addition, the work order had no clear path to move from steps in one group or work order to steps in another group or work order.

All data entries were represented by tests where the answers indicate success if they fall within the allowed range. If the range is narrowed to a certain value, then a success occurs only if the desired value is inserted. The answer to the test questions were found to fall into five categories: value, time, Boolean, text, or select from multiple choices. The success or failure state of the tests determined how the work flow proceeded.

5. CONCLUSIONS

The scenario development performed in this study succeeded in identifying 50 functions that could impact the current work process. These functions build on the currently identified functions as part of the eWP effort by relying further on II&C technologies that have not been utilized. The vast majority of these functions can be developed with current or near-future technological advancement. Their actual impact in terms of efficiency, cost saving, and human error remains unknown; however, the survey conducted as part of this study demonstrated the desire for industry to adopt such functions.

The survey results demonstrated that industry is interested in improving work process efficiency. This was concluded due to the fact that the parts of the process that were manual, time consuming, and human dependent were the parts identified as not working well. To the research team, this indicated that the AWP mission of enhanced process automation aligns with industry need. This was further confirmed by industry interest in the vast majority of the surveyed functions.

The back-end design was found to require key design principles. Several iterations were made to reach the conclusion of the need for these principles. Hierarchy of data architecture was the first realized principle of design. The hierarchy was based on the work package being the top of the hierarchal tree and the step with its properties being the bottom end of the hierarchal tree.

The need for segregation of data architecture by functionality was the second principle of data architecture design. Live data are data that can be accessed by field workers and schedulers, while configuration data are for planners. This principle clearly isolates the data access requirement of each user, which enhances performance of data acquisition and facilitates better data security. This principle also results in archiving efficiency. The live tables' entries cannot be deleted or edited (after work completion) because they log the actual actions information. The configuration tables can be modified any time.

The replication of templates to instances was another design principle that needs to be implemented in the data architecture to allow the planner to better use already developed elements of the data architecture. It was concluded that adopting the object-oriented programming data structures provided an applicable solution to enable this principle.

The introductions of means to allow a flexible instructions flow of the work package was another design principle targeted in this study. Branching of the work package into sequential or parallel steps, groups, and work orders required enabling a logical structure of step execution. The logic needed at this stage was identified as simple "and," "or," and "negate" gates. The data structure behind these gates was found to mainly describe their links to each other and to steps.

The concept and association of properties was developed using a set of design criteria to determine the best property architecture. It was concluded that it is more efficient to associate these properties with the step level, which might seem less efficient at the early stage of work package migration to AWP, but are very efficient once the templates are built.

Development of the back-end has to account for the feasibility of interfacing the back-end to the front-end. This is another design principle that was found during this study. It was realized that the development of the back-end has to allow the flexibility of the front-end design and functions. It was also concluded that as the data structure complexity and storage requirement increases, the interface of the front end becomes easier. This is a typical development optimization dilemma. An ideal design of the data structure would depend on the size of the system. In the case of AWP, the size of the configuration data structure is expected to converge after sometime, while the size of the live data structure will continue to grow due to archiving.

Implementation of the data architecture to a sample work order resulted in several direct benefits. The main finding of the implementation effort was that the majority of the work order forms were eliminated and its size was significantly reduced. This was realized, because most of the information entry and evaluation processes can be automated. The implementation of a sample work order also resulted in several findings that could optimize the performance of work orders.

6. PATH FORWARD

According to this study, the envisioned path to move forward is to complete prototype development through integration of the front-end developed as part of the computer-based procedures effort, with the back-end developed in this effort.

Once the prototype is completed, the most promising and most industry desired functions identified in this study will be developed as part of the prototype. This effort will imply developing new applications for advanced II&C technologies in AWP and performing human factor studies to evaluate the benefit of these technologies.

The long-term vision of this project is to develop a proof-of-concept AWP prototype, with key functions for industry to use and test, to share the technology development experience with industry as was performed in this study, and to share human factors studies results as was performed by earlier efforts.

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Appendix A
Web Survey

Automated Work Packages - Future Vision

Welcome to the Automated Work Package Survey

Welcome!
This survey targets a future solution for the work package process. Automated Work Packages – the next step after Electronic Work Packages. We are curious about what you think works well in the current paper process and where you see potential for efficiency gains. We would like you to consider the whole process from work request, planning, approvals, task execution, reviews, and archiving.

We ask you to imagine what could potentially be possible in the future.We encourage you to describe a solution where you don't have to consider limiting factors such as current work processes, technology, regulations, or attitudes.
Describe your dream system.

Thank you for participating in our survey. Your feedback is important.

Best regards,
The Idaho National Laboratory Research Team

* 1. Demographics:

Organization (utility and plant): __________

Title/role: __________

1

Automated Work Packages - Future Vision

Describe the current Work Package process

The life-cycle process of a work package contains many different parts and involves multiple roles (e.g., Planners, Supervisors, and Craft). To study the work package process and identify potential process improvements it is important to start out by identifying which parts currently work well.

The work package process and its parts used throughout this survey are based on the EPRI report "Improving the Execution and Productivity of Maintenance with Electronic Work Packages" (3002003043).

* 2. Which parts of the work package process work well today?
(Check all that apply)

- [ ] Initiation of work request
- [ ] Screening work requests
- [ ] Planner creates the work package
- [ ] Plan and conduct pre-implementation walkdown
- [ ] Supervisor selection and assignment of work package to Craft
- [ ] Validation of Craft's qualifications
- [ ] Conduct Pre-job brief
- [ ] Verify the current revision of all documents in the work package
- [ ] Walkdown clearance to verify properly hung clearance tag(s)
- [ ] Sign-on clearance and update the oeprations clearance database
- [ ] Receive Operations' permission to start work
- [ ] Sign onto appropriate Radiation Work Request
- [ ] Perform work activity
- [ ] Sign-off clearance
- [ ] Supervisor review
- [ ] Work package disassembly
- [ ] Filing of QA records
- [ ] Archiving
- [ ] Other (please specify)

2

3

Automated Work Packages - Future Vision
Describe the current Work Package process

4

3. Please briefly describe what works well in the parts of the process you selected.

Initiation of work request	
Screening work requests	
Planner creates the work package	
Plan and conduct pre-implementation walkdown	
Supervisor selection and assignment of work package to Craft	
Validation of Craft's qualifications	
Conduct Pre-job brief	
Verify the current revision of all documents in the work package	
Walkdown clearance to verify properly hung clearance tag(s)	
Sign-on clearance and update the oeprations clearance database	
Receive Operations' permission to start work	
Sign onto appropriate Radiation Work Request	
Perform work activity	
Sign-off clearance	
Supervisor review	
Work package disassembly	
Filing of QA records	
Archiving	
Other (please specify)	

5

Automated Work Packages - Future Vision

Describe the current Work Package process

In addition to understanding what works well in the process, it is also important to understand where and how improvements can be made. Your input to the following questions will be a great help to the INL researchers as they design the work package process of the future.

* 4. Where in the process do you think the greatest efficiency gain can be made? (Check all that apply)

- [ ] Initiation of work request
- [ ] Screening work requests
- [ ] Planner creates the work package
- [ ] Plan and conduct pre-implementation walkdown
- [ ] Supervisor selection and assignment of work package to Craft
- [ ] Validation of Craft's qualifications
- [ ] Conduct Pre-job brief
- [ ] Verify the current revision of all documents in the work package
- [ ] Walkdown clearance to verify properly hung clearance tag(s)
- [ ] Sign-on clearance and update the oeprations clearance database
- [ ] Receive Operations' permission to start work
- [ ] Sign onto appropriate Radiation Work Request
- [ ] Perform work activity
- [ ] Sign-off clearance
- [ ] Supervisor review
- [ ] Work package disassembly
- [ ] Filing of QA records
- [ ] Archiving
- [ ] All of the Above
- [ ] Other (please specify)

6

Automated Work Packages - Future Vision

Describe the Work Package System of the future

* 5. If you were to make the work package process more efficient, which parts of the process would you Automate, Remove, Change in some way (other than by automation), or Keep it as it currently is?

	Automate	Remove	Change (but not automate)	Keep as is
Initiate work request	○	○	○	○
Screening work requests	○	○	○	○
Planner creates work package	○	○	○	○
Plan and conduct pre-implementation walkdown	○	○	○	○
Supervisor selection and assignment of work package to Craft	○	○	○	○
Validation of Craft's qualifications	○	○	○	○
Conduct pre-job brief	○	○	○	○
Verify the current revision of all documents in the work package	○	○	○	○
Walkdown clearance to verify properly hung clearance tag(s)	○	○	○	○
Sign-on clearance and update the operations clearance database	○	○	○	○
Receive Operation's permission to start work	○	○	○	○
Sign onto appropriate Radiation Work Request	○	○	○	○
Perform work activity	○	○	○	○
Sign-off clearance	○	○	○	○
Supervisor review	○	○	○	○
Work package disassembly	○	○	○	○
Filing of QA records	○	○	○	○
Archiving	○	○	○	○

Comments:

Automated Work Packages - Future Vision

Describe the Work Package System of the future

6. Please briefly describe the changes needed to improve the efficiency.

Initiate work request	
Screening work requests	
Planner creates work package	
Plan and conduct pre-implementation walkdown	
Supervisor selection and assignment of work package to Craft	
Validation of Craft's qualifications	
Conduct pre-job brief	
Verify the current revision of all documents in the work package	
Walkdown clearance to verify properly hung clearance tag(s)	
Sign-on clearance and update the operations clearance database	
Receive Operation's permission to start work	
Sign onto appropriate Radiation Work Request	
Perform work activity	
Sign-off clearance	
Supervisor review	
Work package disassembly	
Filing of QA records	
Archiving	

8

9

Automated Work Packages - Future Vision

Describe the Work Package System of the future

* 7. Which of the listed capabilities would help increase the efficiency of the work package process? (Check all that apply)

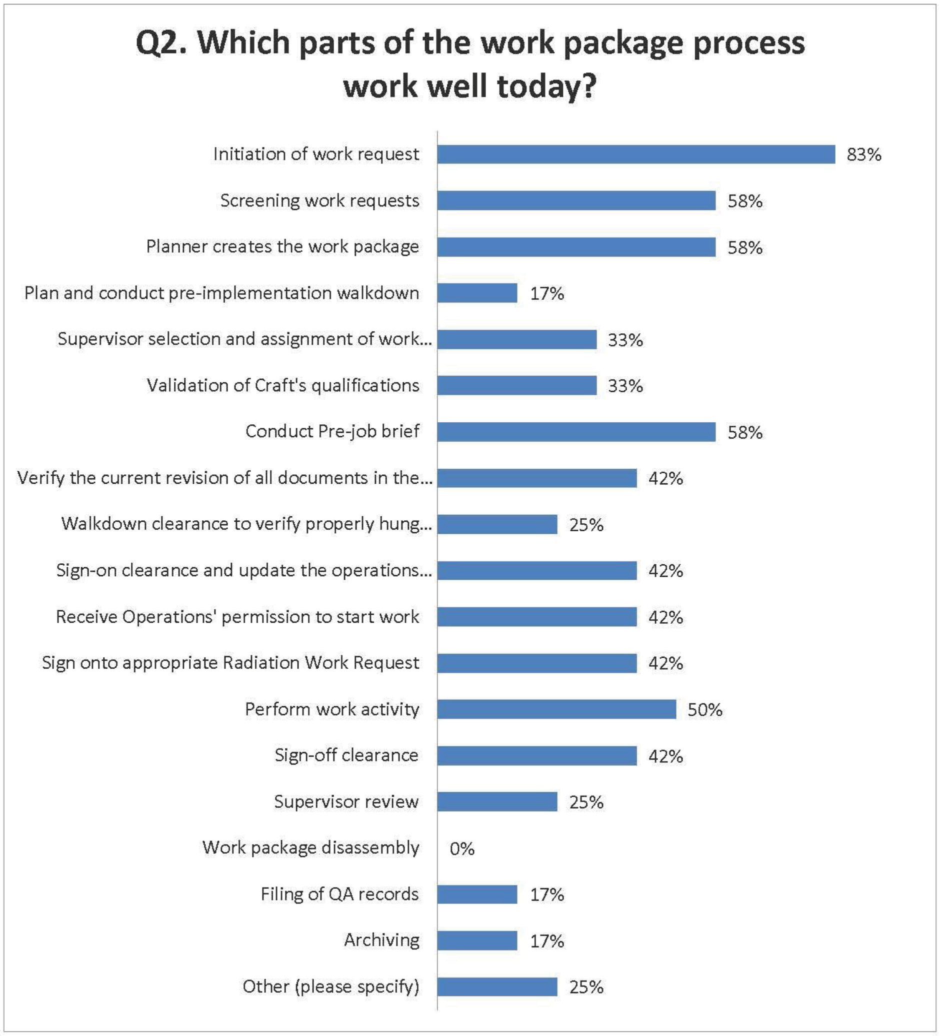
- [ ] Integration of enterprise asset management system and/or work management system
- [ ] Historical data collection of equipment failures
- [ ] Automatic population of work package information including assigned Craft, tools, spare-parts, equipment, and documents
- [ ] Automatic acquisition of plant information
- [ ] Automatic scheduling of tasks according to the available resources, priorities, and state of the plant
- [ ] Automatic integration of plant risk information during Planning
- [ ] Automatic tracking of taskprogress
- [ ] Automatic allocation and release of tools and equipment
- [ ] Pre-recorded pre-job brief videos for frequently performed tasks
- [ ] Automatic scheduling and guidance of walk-downs and pre-implementation walk-downs
- [ ] Automatic placement and/or removal of hold points
- [ ] Automatic tracking of Craft'slocation
- [ ] Automatic notifications to Supervisors, Operations, and other relevant entities as required
- [ ] Voice assisted instructions (e.g.,talk-to-text)
- [ ] Remote access of task progress to all involved entities
- [ ] Remote video monitoring of task execution
- [ ] Automatic notification to resources for QA and other validations
- [ ] Automatic evaluation of Craft's performance
- [ ] Automatic reassignment of tools when not needed
- [ ] Location tracking of tools and spare parts
- [ ] Automatic tool recall for calibration or disqualification
- [ ] Augmented reality (e.g., technology similar to Google glasses)
- [ ] Ability to change level of detail in the work instruction based on Craft's experience and preference

Other and/or Comment:

10

Thank you for your time and input!
Have a great day.

Appendix B
Survey Results



Others (please specify):

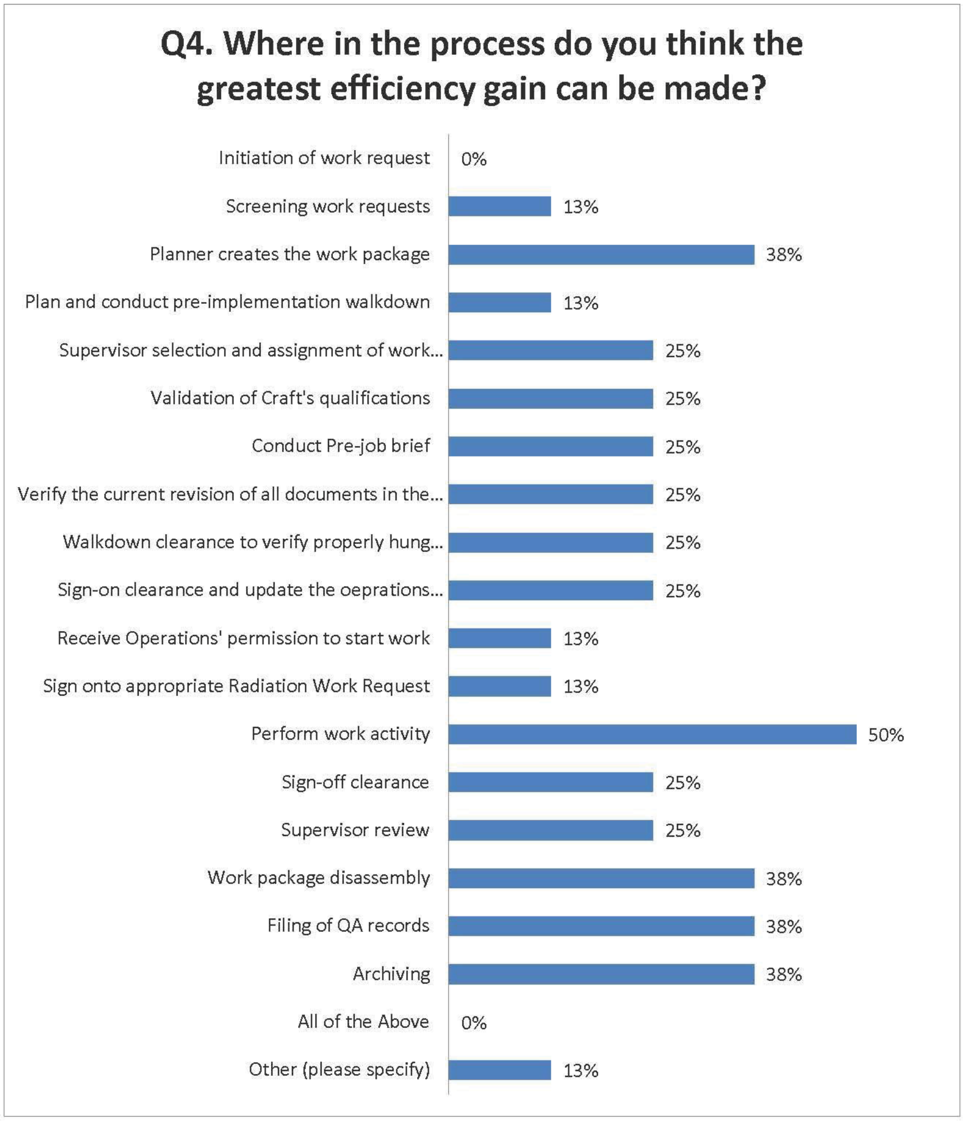
1. The process is still fairly new (using eWP). Folks struggle. Things are not being performed consistently across the station.
2. Scheduling software update.
3. Odd question. All our processes work well by today's standard. Any could use improvement.

Q3. Please briefly describe what works well in the parts of the process you selected.

Item	Comments
Supervisor selection and assignment of work package to Craft	• Dedicated workflow available for the planner to assign WP to adequate crew • All performed electronically
Validation of Craft's qualifications	• Done on every job, manual activity. • Done through a link between site control access system and work management system • External
Conduct Pre-job brief	• Information related to PJB based on INPO and EDF requirements is available to working team through dedicated system. However, we are looking for a more integrated system. • Graded approach • Pre job brief is automatically loaded into every eWP. • Standards and Expectation Booklet is used during pre-job brief
Verify the current revision of all documents in the work package	• Automated links between WP management software and documentation software is efficient • Performed in eWP via Wi-Fi
Walkdown clearance to verify properly hung clearance tag(s)	No Comments
Sign-on clearance and update the operations clearance database	• foreman is required to sign-on in clearances' office close to MCR

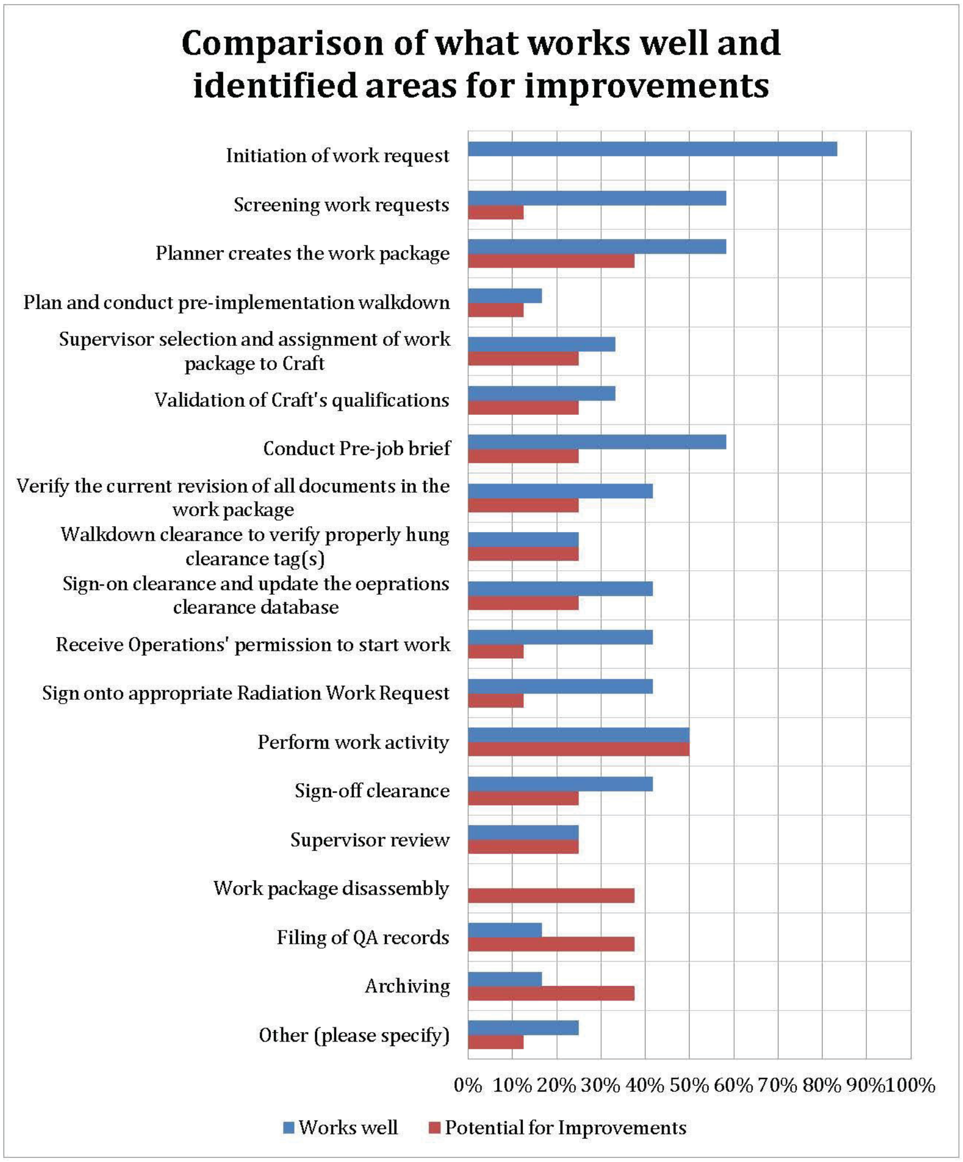
Item	Comments
Supervisor selection and assignment of work package to Craft	• Dedicated workflow available for the planner to assign WP to adequate crew • All performed electronically
Validation of Craft's qualifications	• Done on every job, manual activity. • Done through a link between site control access system and work management system • External
Conduct Pre-job brief	• Information related to PJB based on INPO and EDF requirements is available to working team through dedicated system. However, we are looking for a more integrated system. • Graded approach • Pre job brief is automatically loaded into every eWP. • Standards and Expectation Booklet is used during pre-job brief
Verify the current revision of all documents in the work package	• Automated links between WP management software and documentation software is efficient • Performed in eWP via Wi-Fi
Walkdown clearance to verify properly hung clearance tag(s)	No Comments
Sign-on clearance and update the operations clearance database	• foreman is required to sign-on in clearances' office close to MCR

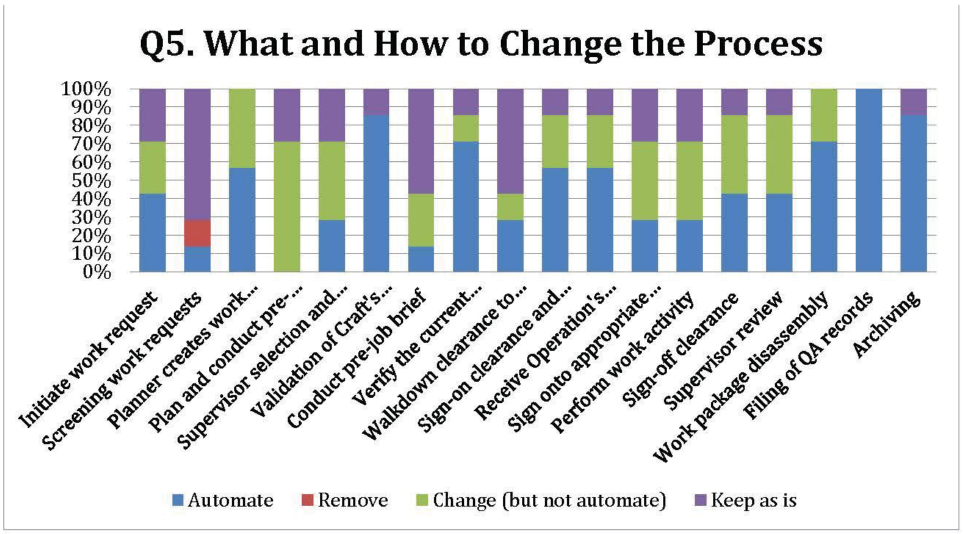
Item	Comments
Receive Operations' permission to start work	• done on all work • foreman is required to sign-on in clearances' office close to MCR just before starting work • Some ahead of time and others through WEC/WCC • Operations signs off during electronic routing of work order
Sign onto appropriate Radiation Work Request	• electronic and prevents most errors • RP assigns REP before work order is routed to craft
Perform work activity	• Per work instructions • Performed on a iPad • Package is assembled and delivered to craft to implement
Sign-off clearance	• same process as sign-on • Done electronically
Supervisor review	• A dedicated document is provided to the supervisor • Performed on a iPad
Work package disassembly	No Comments
Filing of QA records	• Automatically routed electronically
Archiving	• All filled-up documents are scanned in the documentation system. It's in accordance with regulator requirements related to long term storage. • electronic
Other (please specify)	



4. Assembly of the Work Package (note this is after the Planner completes his work. Someone manually puts work orders in binders with separation tabs.

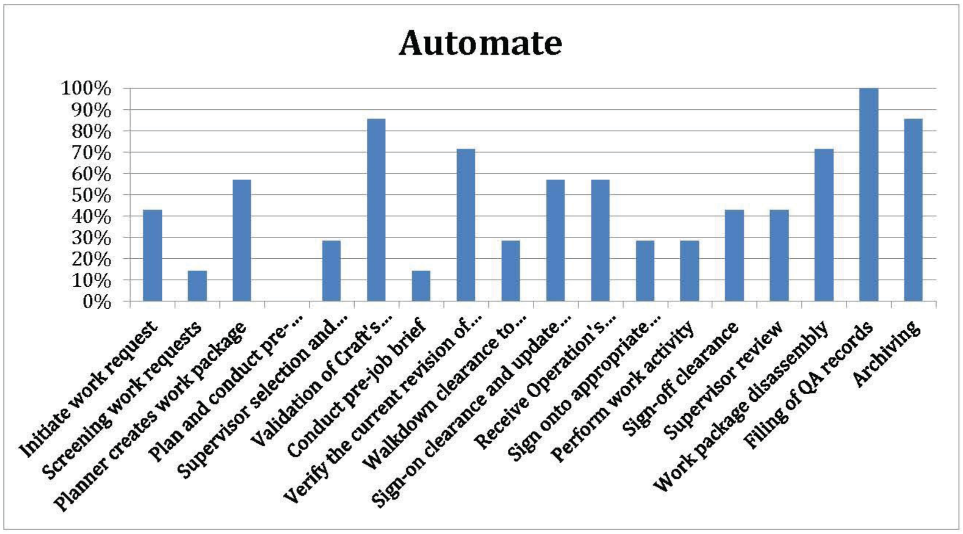
Comparing Q2 and Q4



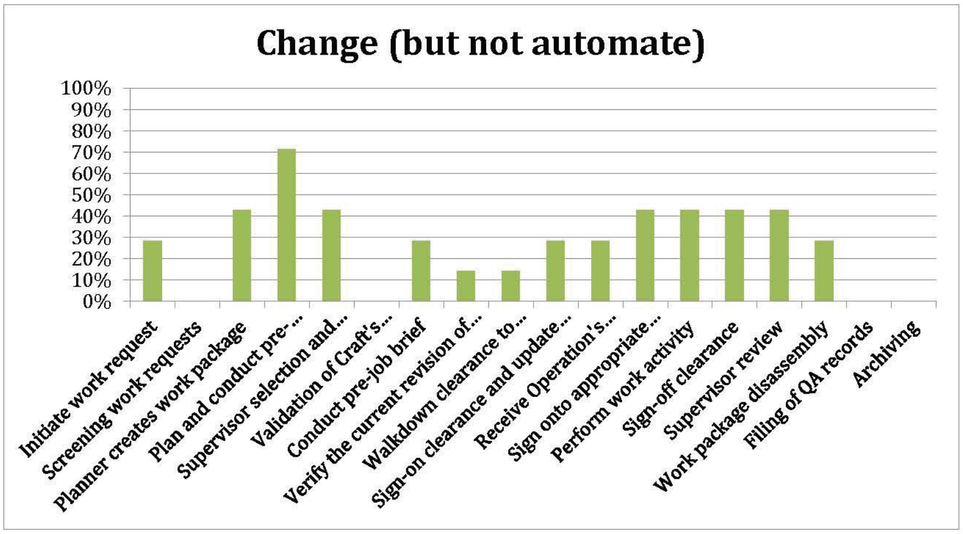


1. Automation of "Perform work activity" should include live status of plant configuration. This would allow the craft to verify what they have done responds in the correctly. This would be verification of, valve positions, alarm responses, breaker positions, equipment actuations, etc….

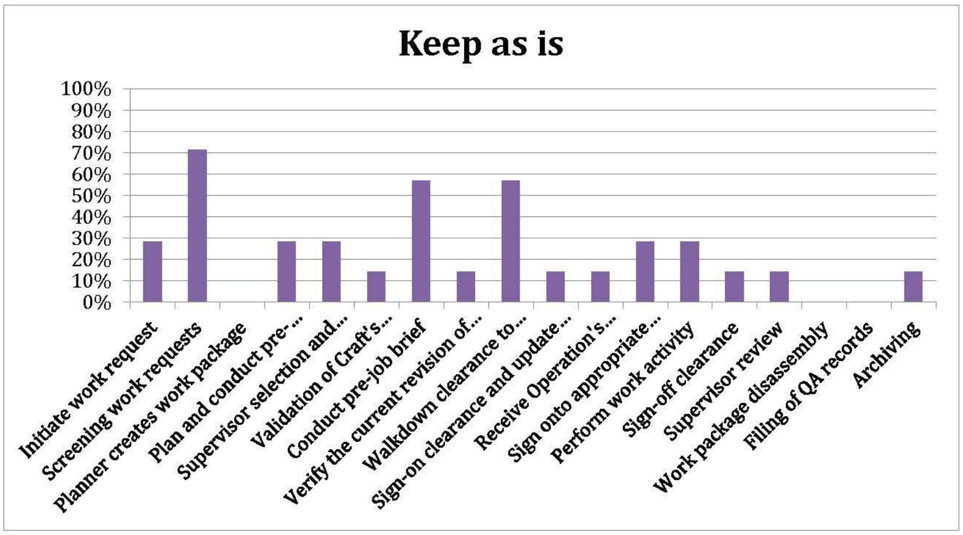
Q5. Result: Automate



Q5. Result: Change but not automate results



Q5. Result: Keep as is

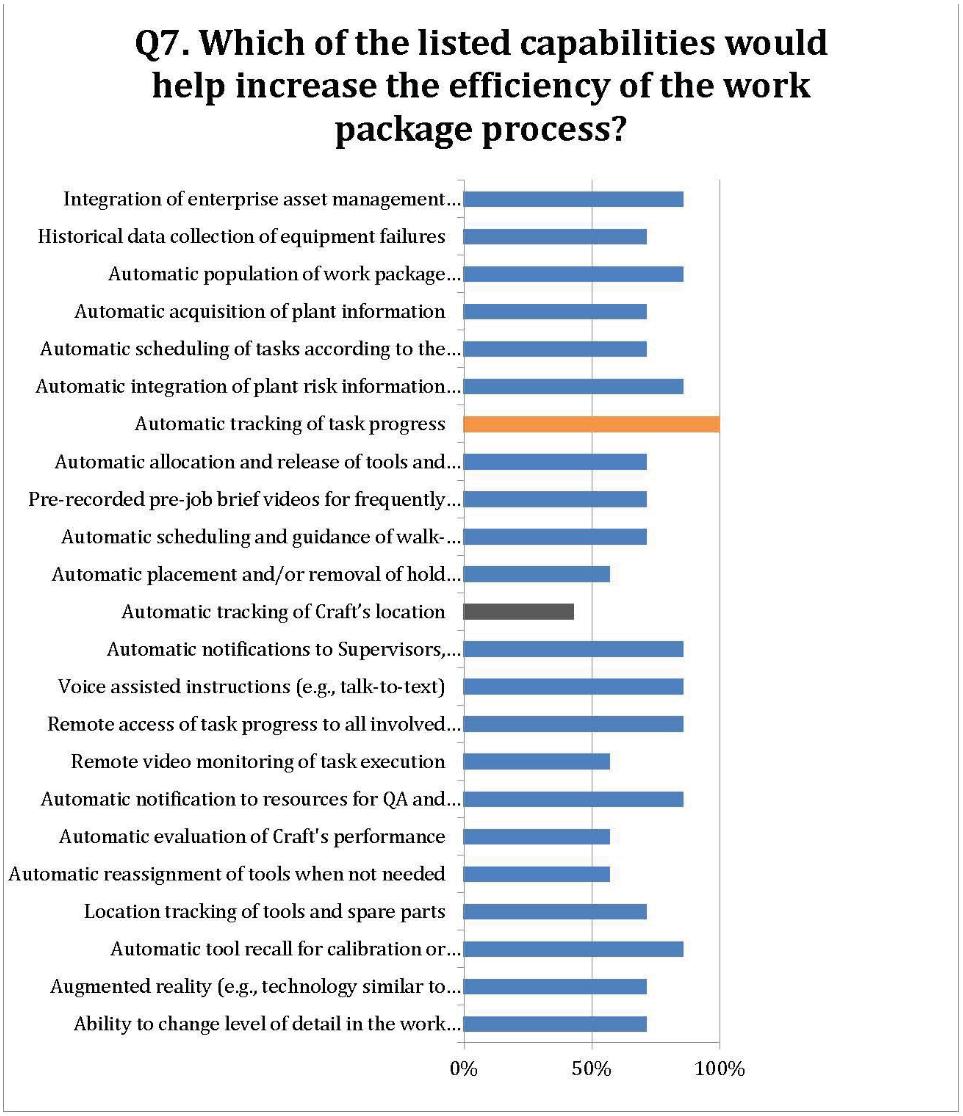


Q6. Please briefly describe the changes needed to improve the efficiency

Item	Comments
Initiation of work request	• Could be done within eWP
Screening work requests	No Comments
Planner creates the work package	• With automation, the planner could build in logic that could change automatically if needed, help the planner create instructions without performing extensive research. • Planner needs to be building smart instructions • Planner has to know what procedures are available for the work that needs to be performed.
Plan and conduct pre-implementation walkdown	• Standardize and make the checklist smaller. • Integration of all needs to perform work, including logistics, RP... • Walkdown information needs to be documented in the field • Work order/parts may not be ready in time
Supervisor selection and assignment of work package to Craft	• make this part of the work scheduling by the discipline scheduler • Not entirely sure the Supervisor's job will be easier. Need to watch this area. May create a bigger burden.

Item	Comments
Validation of Craft's qualifications	No Comments
Conduct Pre-job brief	• Standardize and smaller checklist • Automate (smart form) and standardize PJB
Verify the current revision of all documents in the work package	• Automate where possible
Walkdown clearance to verify properly hung clearance tag(s)	• Use ESoms
Sign-on clearance and update the operations clearance database	• Sign on and off capabilities in the field • Process seems cumbersome here
Receive Operations' permission to start work	• Alter process to allow quicker reviews • Use of mobile devices to avoid foremen to go systematically to clearances' office.

Item	Comments
Sign onto appropriate Radiation Work Request	• automate where possible • simplification of the actual workflow. Use of mobile devices • Uses different program than the work order process
Perform work activity	• automate step approval • simplification of maintenance procedures. USE OF STRUCTURED DOCUMENTS. • Remove the paper bulk, display instructions based on conditional answers/signoffs.
Sign-off clearance	• automation • Sign on and off capabilities in the field • Process seems cumbersome here
Supervisor review	• make it available electronically • Automate review so Supervisor sees missing info. Not a 100% detailed review. • Hard copy has to be reviewed
Work package disassembly	• Any backend stuff becomes easier when automated
Filing of QA records	No Comments
Archiving	No Comments
Other (please specify)	No Comments


Q7. Which of the listed capabilities would help increase the efficiency of the work package process?
Integration of enterprise asset management…
Historical data collection of equipment failures
Automatic population of work package…
Automatic acquisition of plant information
Automatic scheduling of tasks according to the…
Automatic integration of plant risk information…
Automatic tracking of task progress
Automatic allocation and release of tools and…
Pre-recorded pre-job brief videos for frequently…
Automatic scheduling and guidance of walk-…
Automatic placement and/or removal of hold…
Automatic tracking of Craft's location
Automatic notifications to Supervisors,…
Voice assisted instructions (e.g., talk-to-text)
Remote access of task progress to all involved…
Remote video monitoring of task execution
Automatic notification to resources for QA and…
Automatic evaluation of Craft's performance
Automatic reassignment of tools when not needed
Location tracking of tools and spare parts
Automatic tool recall for calibration or…
Augmented reality (e.g., technology similar to…
Ability to change level of detail in the work…
0%
50%
100%

Appendix C
Properties Assignment to the AWP Tree Elements

Table 1. Step association according to the concepts defined in the data architecture.

Object	Template versus Instance	Configuration versus Live	External Properties	Internal Properties
Step	Template	Configuration	Discipline Document Expertise Hazard Material Note Caution Review Risk Tag Test Tool Training	ID DescriptionLevel1 DescriptionLevel2 DescriptionLevel3 Voice ExecutionTime Priority ReactorImpact SeismicCatagory IssueProbability Critical Revision
	Instance	Configuration	Group.Template Group.Instance Material.Item Risk Tag	ID TemplateID ExecutionTime Priority ReactorImpact SeismicCatagory IssueProbability Critical Revision
		Live	Staff Error Discipline Material Note Risk Test Tool	ID ConfID Status StatusTimeStamp StartTimeStamp EndTimeStamp ProblemOccured

Table 2. Group association according to the concepts defined in the data architecture.

Object	Template versus Instance	Configuration versus Live	External Properties	Internal Properties
Group	Template	Configuration	Tag Review	ID DescriptionLevel1 DescriptionLevel11 DescriptionLevel12 ExecutionTime Priority ReactorImpact SeismicCat IssueProbability Critical Revision
	Instance	Configuration	Group.Template Group.Insatance WorkOrder.Template WorkOrder.Instance Tag	ID TemplateID ExecutionTime Priority ReactorImpact SeismicCat IssueProbability Critical Revision
		Live	Review	ID ConfigID Status StatusTimeStamp StartTimeStamp EndTimeStamp ProblemOccured

Table 3. Work order association according to the concepts defined in the data architecture.

Object	Template versus Instance	Configuration versus Live	External Properties	Internal Properties
Work Order	Template	Configuration	Tag	ID
			Review	Name
				Objective
				DescriptionLevel1
				DescriptionLevel2
				DescriptionLevel3
				ExecutionTime
				ClearanceRequired
				ClearanceStandard
				RCSPert
				SCFDRequired
				SCFDDocumentID
				WSL
				CRDL
				PriorityID
				ReactorImpact
				SeismicCat
				IssueProbability
				Critical
				Revision
	Instance	Configuration	WorkPackage.Template	ID
			WorkPackage.Insatance	TemplateID
			Tag	ExecutionTime
				SeismicCat
				IssueProbability
				Priority
				ReactorImpact
				Critical
				Revision
		Live	Review	ID
				ConfigID
				Status
				StatusTimeStamp
				StartTimeStamp
				EndTimeStamp
				ProblemOccured

Table 4. Work package association according to the concepts defined in the data architecture.

Object	Template versus Instance	Configuration versus Live	External Properties	Internal Properties
Work Package	Template	Configuration	Tag Review	ID Name Objective DescriptionLevel1 DescriptionLevel2 DescriptionLevel3 ExecutionTime TypeID SubTypeID Priority ReactorImpact SeismicCat IssueProbability Critical Revision
	Instance	Configuration	Tag	ID ClassID ExecutionTime SeismicCat IssueProbability Priority ReactorImpact Critical Revision
		Live	Review	ID ConfID Status StatusTimeStamp StartTimeStamp EndTimeStamp ProblemOccured

Table 5. Work request association according to the concepts defined in the data architecture.

Object	Template versus Instance	Configuration versus Live	External Properties	Internal Properties
Work Request	Template	Configuration	WorkPackage.Template	ID Description Frequency Cycel
	Instance	Configuration	WorkPackage.Instance	ID TemplateID Frequency Cycel
		Live		ID ConfigID InitiatorType InitiatorStaff InitiationTimeStamp Priority Due HundredPercent Expiration SpecialConcerns

Table 6. The step sequence properties.

Object	Temp. Vs Instance	Configuration Vs Live	External Properties
Step	Instance	Configuration	AndID
			OrID
			StepInstanceID
			InvertInput

Appendix D
Example Properties to Properties Association Tables

Table 7. Material item live properties.

Object	Temp. Vs Instance	Configuration Vs Live	Internal Properties
Material.Item	Instance	Live	Latitude
			Longitude
			Altitude
			AvailableFlag

Table 8. MTE item live properties.

Object	Temp. Vs Instance	Configuration Vs Live	Internal Properties
MTE.Item	Instance	Live	Latitude
			Longitude
			Altitude
			CalibrationTimeStamp
			NextCalibrationTimeStamp

Table 9. Step-discipline configuration association table.

Object	Temp. Vs Instance	Configuration Vs Live	Internal Properties
Step-Discipline	Template	Configuration	ActionRequiredFlag
			AcknowledgementRequiredFlag
			NotificationRequiredFlag
			ClearanceRequiredFlag
			ClosureRequiredFlag

Table 10. Step-discipline live association table.

Object	Temp. Vs Instance	Configuration Vs Live	Internal Properties
Step-Discipline	Instance	Live	ConfigID
			ActionTimeStamp
			AcknowledgementTimeStamp
			NotificationTimeStamp
			ClearanceTimeStamp
			ClosureTimeStamp