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A Process Modeling Methodology for Automation of Manual and Time Dependent Processes

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ABSTRACT
Traditional functional modeling methodologies tend to look at the decomposition of a physical artifact, system, or subsystem, but these techniques are just as applicable to processes, manual operations, and human-centric procedures. A process, when decomposed into its most basic tasks and events, resembles the products traditionally modeled using functional modeling. The aim of this paper is to present a methodology to model such processes utilizing functional modeling techniques. Process models allow for the mapping of an operation to ensure desired outputs are achieved at specific times (or after certain time durations), goals are met, critical paths are followed, and efficiency is increased. The proposed process modeling methodology is further explored as a tool to understand and identify what elements of a manual or human centric process may be automated or solved by some other engineering solution.

1. INTRODUCTION
Often, design projects are viewed as only involving the steps directly related to the formulation of a solution in the form of a physical artifact, system, or subsystem. However, design projects that involve the formulation of automated solutions to replace existing manually operated products or human-centric procedures (e.g., automated solutions to remove personnel from high-risk tasks) require the problem to be framed in a larger context. Here the line blurs between the more traditional design techniques and many existing project management strategies. What becomes important is to understand the *process* to which an engineered solution is sought. To that end, the concept of a process model is explored to clearly identify the elements of a process that can be automated or solved by some engineered solution. More broadly, the process model concept may offer increased capability for traditional project management techniques through a more accurate identification and representation of necessary tasks.

This paper presents a process modeling methodology based on current functional modeling techniques found in many engineering design methodologies [1-10]. Process models as presented employ the Functional Basis developed by Stone and Wood [11] for terminology. The key difference is a new time line feature for task or event scheduling. Taken together, these two characteristics of the process modeling methodology address the fundamental challenges associated with the automation of existing products and processes and add detail to existing project management techniques.

The motivation for process modeling stems from an United States (US) Army project where both the current US Nuclear, Biological and Chemical (NBC) decontamination procedure for troops and equipment and other commercially available decontamination procedures are being modeled to increase procedure efficiencies and reduce soldier risk. The current NBC decontamination procedure is both tried and proven, but it has considerable logistical drawbacks. It is the aim of the investigators to utilize process models of the current decontamination process and of other commercially available decontamination solutions to alleviate these drawbacks. The design of the NBC decontamination procedure attacks the problem with brute force, and thus it is resource expensive. It uses large amounts of personnel, water, and decontaminates which are all a scarce commodity on the battlefield. NBC decontamination also presents considerable logistical problems. Along with bringing all required decontamination supplies, a decontamination site must be chosen and prepared where troops and supplies can safely rendezvous and decontamination can be performed. During the decontamination procedure, there is considerable risk to soldiers, decontamination crews, and the environment due to the accidental spread of NBC contaminates.

The current Army NBC decontamination procedure consists of two major processes, detailed equipment decontamination (DED) and detailed troop decontamination (DTD). Each can be broken down into different segments with an overall goal of decontamination. The decontamination procedure lends itself well to a task breakdown process, with each major segment decomposed into tasks and events where all the tasks and events together complete the overall segment goal. This analysis of the procedure identifies repetitive steps in each task. Analysis of the repetitive steps reveals opportunities to use automation and robotic manipulation to minimize personnel exposure to toxic agents.

NBC decontamination can be thought of as the product or final output of a manufacturing process and as such can be broken down like a product utilizing functional modeling techniques. In this paper, a process modeling method is outlined utilizing augmented functional modeling techniques. Process models will utilize the current framework of functional models with the addition of a time line for scheduling process tasks. Steps to develop a process model will be presented, and the benefits to utilizing a functional basis will be addressed. Use of process modeling techniques will then be demonstrated in practice with the Kärcher TEP 90 decontamination system.

2. PRIOR WORK

Process modeling can take numerous forms that range from a project outline, to a schedule, to an activity model. These methods all share at least one commonality; they specify the basic course to lead a process from its inception to its conclusion. This is also referred to as temporal planning.

Numerous methods exist to generate process or project schedules. It is so important that the United States Office of Personnel Management provides a five-step workforce planning model [12]. The purpose of the method is to set up a workable project plan that maps out direction, determines a plan of action, identifies skill gaps in the workforce, and monitors project progress. The workforce planning model consists of the five steps listed below.

- Step 1: Set Strategic Direction
- Step 2: Analyze Workforce, Identify Skill Gaps and Conduct Workforce Analysis
- Step 3: Develop Action Plan
- Step 4: Implement Action Plan
- Step 5: Monitor, Evaluate & Revise

Common project planning methods include Gantt charts, design structure matrices (DSM), and program evaluation and review technique (PERT) charts. The Gantt chart provides a technique for clear, concise project scheduling. Each task is listed versus a time line. A bar that spans from task inception to conclusion represents when the task will be performed. The drawback to a Gantt chart is its inability to easily represent task dependencies and requirements. DSMs eliminate the problem of task dependencies through the use of a matrix with each task listed identically on both row and column headings [13]. Tasks are listed in the order in which they are to occur, and task dependencies are denoted with an X or some other correlation figure or value in the appropriate cell corresponding to each related task. DSMs, however, leave out a useful detail available in Gantt charts; they do not include a methodology for scheduling and timing tasks. PERT charts clear up both the problems of task dependencies schedule timing. PERT charts provide flow lines that connect one task to another. Each task to be completed is within a box along with the time required for completion. The PERT method provides the benefit of tying tasks together to establish dependencies and requirements, with parallel and sequential tasks intrinsically represented. The drawback to both Gantt charts and PERT charts is a lack of methodology to illustrate how specific tasks will be carried out. Without the ability to do internal task planning, there is uncertainty in exact time to completion and the exact output from any given task [1].

Simple activity models provide a methodology that connects tasks through flow. An activity model is similar to a PERT model; however, the temporal data is omitted and the overall focus is different. An activity model focuses on tasks that represent user interactions with a product through its preparation, execution, and conclusion stage. Each task is represented within a box that is connected to other tasks through flow lines. Tasks that are parallel and sequential are intrinsically represented [10].

A workflow planning method proposed in Ju's research work breaks down a process into its subparts, which helps to eliminate problems concerning process methodologies that are inherent with basic temporal scheduling techniques [14]. Ju defines the overall process as a workflow, which can be comprised of one or more subprocesses consisting of work items to be completed. Managers coordinate the subprocesses and have a certain amount of authority over the decisions required to complete a subprocess.

Other research work that investigates workflow or project planning includes Eder and Liebhart's proposed Workflow Activity Model (WAMO) [15]. The WAMO method uses the general idea that any business process can be broken down into smaller working units referred to as workflows, which can again be broken down into smaller subprocesses. These workflows are illustrated through an activity tree. The final WAMO metamodels illustrate the overall business process, and are comprised of all project workflow activity trees.

The aforementioned process or event scheduling methods could benefit from functional modeling techniques. Functional modeling is a proven methodology for clearly and concisely breaking down a product and functionally defining all its component operations. The IDEF0 or Integrated Definition Method #0 provides a framework for developing functional models that can be used to define how elements work together to perform an operation[16]. Elements can be any combination of things like people, information, software, raw materials, or other individual product elements. Because such a wide range of elements can be utilized, a process can be modeled just as easily as an individual product. The IDEF0 method of functional modeling is similar to other functional modeling techniques. Each function is represented with a box named with a verb or verb phrase. Boxes are connected using arrows labeled with a noun or noun phrase, and the flow type is represented by the location of the arrow with respect to the function. Supported flow types include, control, mechanism, call, input and output. Drawbacks to the IDEF0 method of functional modeling include its limited ability to define time requirements in process models and its inability to ensure uniform understanding for each person to analyze a functional model. The IDEF0 method was not originally designed to model activity sequences, so it does not make any attempt to capture the time requirements that should be included in a process model. It also lacks a structured language base that limits the verbs and nouns that can be utilized to represent functions and flows. Since many of the words in the English language have connotative meaning beyond the standard denotative meaning, the exact intention of a function could be misinterpreted depending on the individual analyzing the functional model.

A functional modeling technique that overcomes the language shortfalls of IDEF0 is functional modeling with the Functional Basis as developed by Stone and Wood [11, 17]. The Functional Basis utilizes a standardized language, which supports consistent understanding [18]. As in IDEF0, functions are represented graphically with a box that contains the function required to complete an overall objective. Each box is labeled in verb-object pairs, where the verb is the function and the object is the flow. Each operation, or function, carried out on these flows is represented by a function term categorized at primary, secondary, and tertiary levels of detail. Flows between functions are categorized either as energy, material, or signal. At a secondary level, it can be specified whether these are human, mechanical, electrical, hydraulic, etc. Each flow and function is precisely defined to ensure clarity in what will carry out a function and how it will be performed [17]. Functional modeling techniques utilizing the Functional Basis allow for clearer understanding of each event in an overall process model. Where Gantt and PERT charts and other temporal methods lack task methodology, functional modeling inherently provides this data with flow type and function, which clarifies exact task methodology. This leaves little doubt in how a task should be performed and who or what will perform that specific task. Clearer task understanding ensures more uniform output, which increases productivity through better process efficiency.

3. RESEARCH APPROACH

The underlying hypotheses of this work are (1) that processes can be more systematically modeled using a time-augmented functional modeling methodology and (2) that such process models will identify process segments that can be solved with automated solutions. In the next section, the observations that lead to the formulation of these hypotheses are explored. Following that, a process modeling methodology is formulated to support testing of the hypothesis.

3.1 Comparison with Functional Models

A process, when broken down into its most simple events, resembles the basic functional decomposition of a product. The flow of a process can be modeled in much the same way as a product utilizing functional modeling techniques. Through minor augmentation, functional modeling techniques can be used to capture the required spatial and time dependencies of a process.

A process model differs from a traditional functional model in that it develops an outline for a specific series of actions or operations that are performed through both a spatial and time domain to deliver a desired final outcome. In this sense, a process model is like an assembly line where a series of events are occurring to deliver a desired outcome or product. A functional model, however, explores an individual product's functionality by breaking its overall functionality or purpose down into a more basic level of required operation. These steps are referred to as subfunctions.

Functions and subfunctions consist of verb-object pairs where the verb represents a specific function and the object represents the specific flow. A process model follows the same format of breaking down the operation into its most basic process events, and these process events are like functions in a functional model. Process events also consist of verb-object pairs where the verb is the process event and the object is the flow.

3.2 Process Models Defined

Formally, we define a process model as a collection of elemental tasks and events related through common input/output flows tied together in both spatial and time domains. The following terms related to process modeling are used throughout the paper.

- *Task:* refers to a specific piece of an operation to be carried out.
- *Event:* refers to a specific required occurrence.
- *Process Event:* a description of a task or event that is to be carried out and is expressed as a verb-object pair.
- *Black Box Event:* a high-level process model defined by a single process event describing the overall operation of a series of tasks.
- *Stations:* black box event models that are linked together.
- *Subprocess Event:* a more detailed process event representing an individual task or event that is a component in the high-level black box event.
- *Flow:* a change in material, energy, or signal with respect to time. A flow is the recipient of a station or subprocess event's operation.
- *Time Line:* a representation of the temporal relationship between subprocess events.

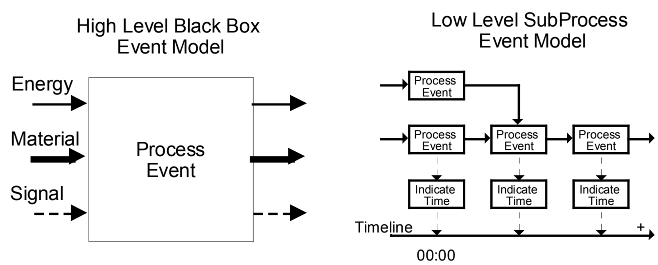

Figure 1: Basic high-level black box event model and a corresponding low level subprocess event model

As with functional models, the process model is formulated in successive levels of detail. The top layer consists of a black box event defining the overall process event to be carried out. See Fig. 1 for an example of a high-level black box event model. Input and output flows required for the process event are drawn going in or out of the black box. There are three flow types: energy, material, and signal. Energy is drawn as a single width arrow, material a bold arrow, and signal a dashed arrow. Each of these arrows should be labeled with the object required to make the verb-object pairs for each import and export flow in the process model. More detailed levels model the subprocesses of a black box event. An example of a low-level subprocess event model

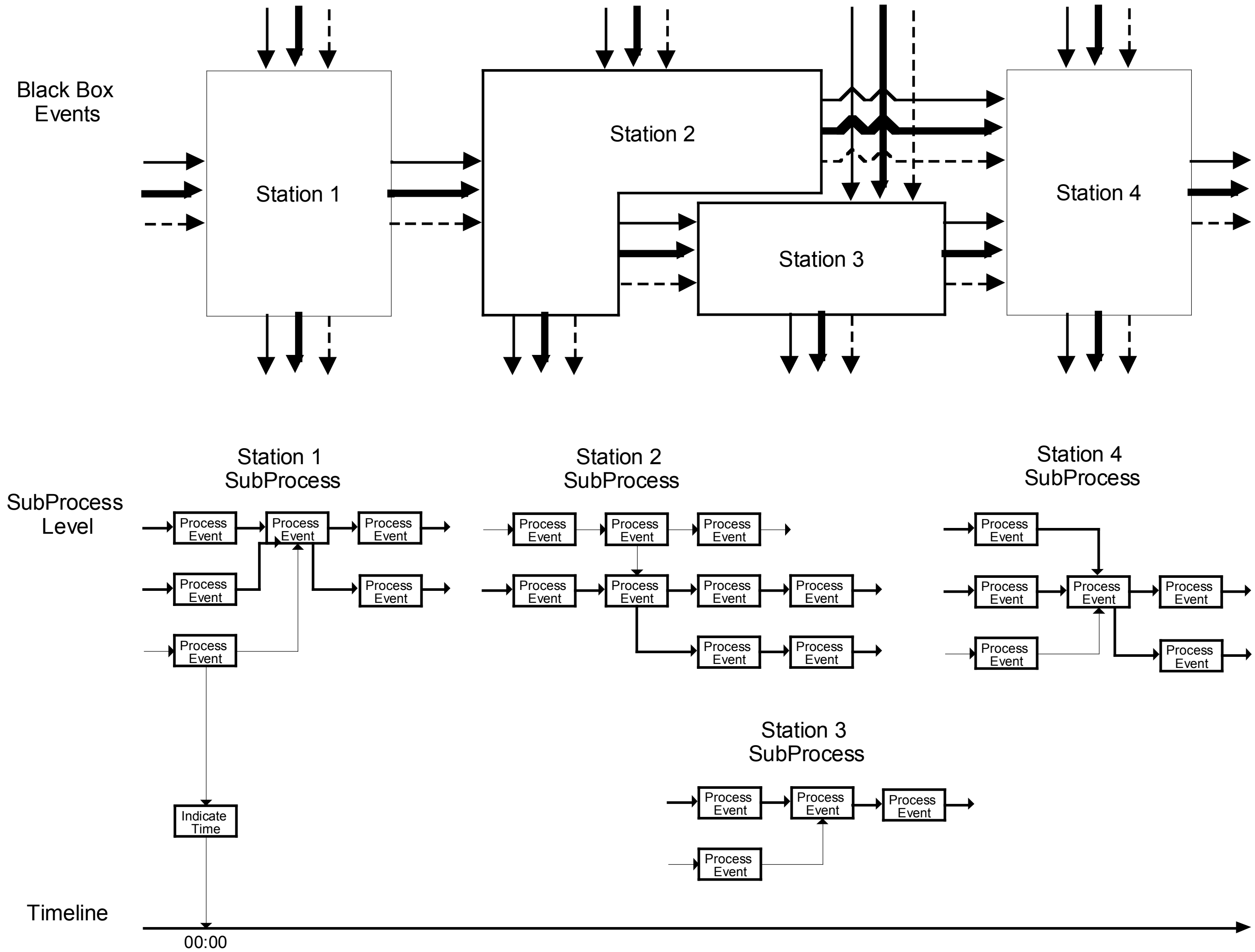

Figure 2: Layout of black box models as stations with respect to time and corresponding subprocess event models

is also provided in Fig. 1. A subprocess model is developed by first importing the material, energy, and signal flows required to carry out the specific process for each black box event. Then using the Functional Basis developed by Stone and Wood [17], chains of process events are developed for each flow from the input to the final output flow.

While a basic functional model may contain some temporal information in the basic sequencing of functions, event timing is not explicitly represented. To include the basic temporal information for task and event timing, a subprocess event is drawn parallel to a time line with initiation time at the left, parallel to import events, and completion time at the right, parallel to output events. Process event timing can be specific and contain exact dates and times or can be general where the start time is simply represented as 00:00 and the end time is some count of elapsed time. To tie specific process events to the time line, a signal flow is drawn from the desired process event, to the process event, *Indicate* with the flow, *Time*. Another signal flow then connects *Indicate Time* to the time line. At this junction, the desired time to pass is displayed. This can more clearly be seen illustrated in the low-level subprocess event model in Fig. 1. It should be noted that the current Functional Basis as developed by Stone and Wood [17] does not contain a *time* flow though time is consistent with the primary flow signal. The *time* flow has been added for process modeling.

A process model does not have to consist of solely one independent black box event and its subprocess model. It can instead consist of a series of black box events that together represent an overall process. Provided in Fig. 2 is a process model with four separate black box events linked together. Black box event models that are linked together are referred to as stations. Each of these stations can of course be looked at independently since each has its own independent process model. Material, energy, and signal flows that transfer from one station to the next are still represented as bold, thin, and dashed arrows respectively. They would now, however, travel out of one station and into the next. These flows are not required to travel through the stations in a direct sequential order. They could, for instance, skip a station or even feed back to a prior station. For ease of understanding, these flows typically travel into the vertical sides of the black box model of the station.

There are also material, energy, and signal flows that might be exclusive to one station. For instance, a material required for a particular task only performed at one station would probably not flow into other stations. These flows, exclusive to a particular station, typically flow into and out of the horizontal sides of the black box event model of the station as shown in Fig. 2.

By breaking down a process into a series of black box models, a project planner can insure that each station's output will match the expected input for all following stations. This is anticipated to increase the overall process efficiency.

4. Process Modeling Methodology and Analysis

A five-step method that can be followed in the creation of a process model has been developed, and is provided in section 4.1. The method utilizes the Functional Basis, and thus the primary and secondary flow and function classes are provided in abridged form in Tables 1 and 2 respectively. The complete Functional Basis can be found in Hirtz et al. *Reconciled Functional Basis* [11]. To analyze each process model for automation potential, a matrix based product similarity technique is presented in section 4.2. These methods are illustrated in section 5 where they are utilized to generate a process model for the Kärcher TEP 90 decontamination system.

4.1 Methodology

Step 1: Identify process requirements and customer needs.

Step 2: Using the process requirements and customer needs, identify or formulate the tasks necessary to complete the current or proposed process. Associate process requirements and customer needs with their related tasks. Identify input and output flows and start/stop times for each task. Task input/output and time flows should be derived from each process requirement and customer need.

Step 3: Formulate high-level black box event models as verb-object stations. The process model convention for multiple black box event models is to show inter-station flows entering and exiting on the vertical (left & right) sides of the box. Intra-station flows (those used only within that particular station) enter and exit through the horizontal (top & bottom) sides.

Step 4: Decompose black-box event model into more detailed event to generate subprocess event models in verb-object format.

- An appropriate level of detail will be determined by the process requirements and customer needs; at a minimum, however, it should be specific enough to identify duration of process and resources required.
- Show parallel and sequential nature of subprocess events.
- Indicate time dependencies via a time line in a left to right layout.

Step 5: Verify all process requirements and customer needs are addressed by at least one subprocess event.

4.2 Analysis

Following the completion of the process model, an analysis of the subprocess events is conducted to identify repetitive tasks and areas resembling the functionality of robotics. To investigate task similarities and identify areas of potential automation, a matrix methodology for determining product similarities was implemented [20, 21]. The method involves generating a product-function matrix where each product is represented as a vector composed of its own functions. Each product vector is normalized and projected upon all products in the matrix. The result is a matrix of product similarity ratings between the range of zero and one where one is completely similar and zero is completely different. The diagonal of the matrix is the projection of each product upon itself and consists of only ones. In this case, the subprocess events of each station are substituted for the function and the stations are substituted for the product creating a station-process event similarity matrix. Mathematically, the station-process event vectors, ϕ_i, are aggregated in a matrix, Φ. The matrix has dimension n x m, where n is the maximal number of distinct subprocess events

Table 1: Primary and secondary flow classes

Class (Primary)	Material	Signal	Energy		
Secondary	Human	Status	Human	Electrical	Mechanical
	Gas	Control	Acoustic	Electromagnetic	Pneumatic
	Liquid	Time	Biological	Hydraulic	Radioactive
	Solid		Chemical	Magnetic	Thermal
	Plasma				
	Mixture				

Table 2: Primary and secondary function classes

Class (Primary)	Branch	Channel	Connect	Control Magnitude	Convert	Provision	Signal	Support
Secondary	Separate	Import	Couple	Actuate	Convert	Store	Sense	Stabilize
	Distribute	Export	Mix	Regulate		Supply	Indicate	Secure
		Transfer		Change			Process	Position
		Guide		Stop				

observed across the *m* stations. Each vector of Φ is normalized to one using Eqn. 1.

$$n_i = \frac{\phi_i}{\sqrt{(\phi_i^T \cdot \phi)}} \tag{1}$$

Similarity between stations is calculated using Eqn. 2 below where **N** is an aggregation of vectors **n**.

$$\Lambda = N^T \cdot N \tag{2}$$

5. RESEARCH APPLICATION / FINDINGS

As an application of the process modeling methodology to automate manual processes, consider both the current United States Army thorough Nuclear, Biological, and Chemical (NBC) decontamination procedure and the Kärcher TEP 90 decontamination system. While the existence of and the general parameters of the US Army NBC decontamination are publicly known, the specific procedures are not classified for public release. Thus, this paper will only speak in generalities concerning the US Army NBC decontamination process. The process modeling procedure will consequently be applied to the Kärcher TEP 90 decontamination procedure.

5.1 Decontamination Background

While the current NBC decontamination procedure and the Kärcher TEP 90 decontamination system share the same process requirements and customer needs, they are in fact very different processes. Currently, the NBC decontamination procedure is a manual process with no automation, while the Kärcher TEP 90 decontamination procedure is more of an automated human assist procedure that could be an automation solution for the current procedure.

The current NBC decontamination procedure consists of two parts: Detailed Troop Decontamination (DTD) and Detailed Equipment Decontamination (DED). Steps for both of these procedures are very different; their structures, however, are similar. DTD is an eight-station process designed to decontaminate individual soldiers and their gear, while DED is a five-station process for decontaminating vehicular equipment. Both decontamination processes require the contaminated subject to travel through a series of steps or stations to complete the decontamination. The result from each station is the contaminated subject at some point in the decontamination process.

The Kärcher TEP 90 decontamination system is a modular system with three modules collectively containing all supplies required to carry out decontamination of equipment and troops [19]. A schematic of the system is shown in Fig. 3. For vehicular/equipment decontamination the procedure consists of three steps. The first step is a Pre-Treatment phase where visible dirt is removed from the vehicle. This ensures that the gross contaminate contained within the dirt is removed. The second station is a Main-Treatment phase where a decontamination agent is applied. This station uses high-pressure spray and a cherry picker type boom to aid in the agent application. The agent type depends on the type of contamination present. If it is nuclear, then it needs radioactive decontamination; if it is biological, then it needs disinfection; and if it is chemical, then it needs detoxification. The third and final phase of exterior vehicular decontamination is called Post-Treatment. Post-Treatment uses high pressure cold or hot water or steam to remove all left-over decontamination materials. Following exterior vehicular decontamination, the Kärcher TEP 90 decontamination system has a procedure for interior where the interior is sprayed with a decontamination solution that is then promptly suctioned up. Other forms of decontamination that can be carried out with this system include personnel decontamination, personal equipment decontamination, and road and site decontamination.

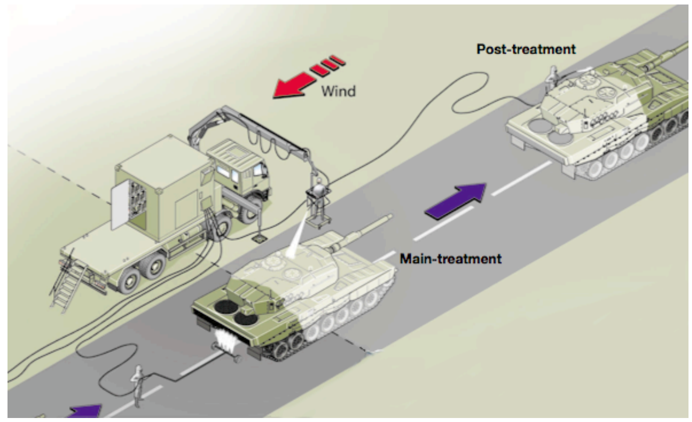

Figure 3: Station 2 (Main-Treatment) and Station 3 (Post-Treatment) of Kärcher TEP 90 decontamination system [19]

For both the current NBC Decontamination procedure and the Kärcher TEP 90 decontamination system, each station's output is the input for each subsequent station. Each station can then be analyzed as a separate product with its own black box event model and subprocess model. In this sense, a decontamination process resembles a factory assembly line.

5.2 Application to Kärcher TEP 90 Decontamination System

Step 1:
The first step to creating a process model is to identify all requirements for decontamination. The US Army provided a list of requirements and needs that are to come out of the process models of all decontamination procedures. This list of requirements and needs are similar for both methods of decontamination considered. It included goals such as increased efficiency, productivity, and accuracy; minimized risk to soldiers, decontamination units, and the environment; and identification of potential areas of automation.

Step 2:
Step two involves identifying the major tasks of the process and mapping customer needs and process requirements to input and output material, signal, and energy flows. A sample of this mapping is shown in Table 3 for the first station of the Kärcher TEP 90 decontamination system. For instance, the material flow contaminated vehicle is mapped to increased efficiency and increased speed of decontamination procedure. The material flow, human, is mapped to minimized risk of soldiers. The human and hydraulic energy flows are mapped to the identification of potential areas of automation.

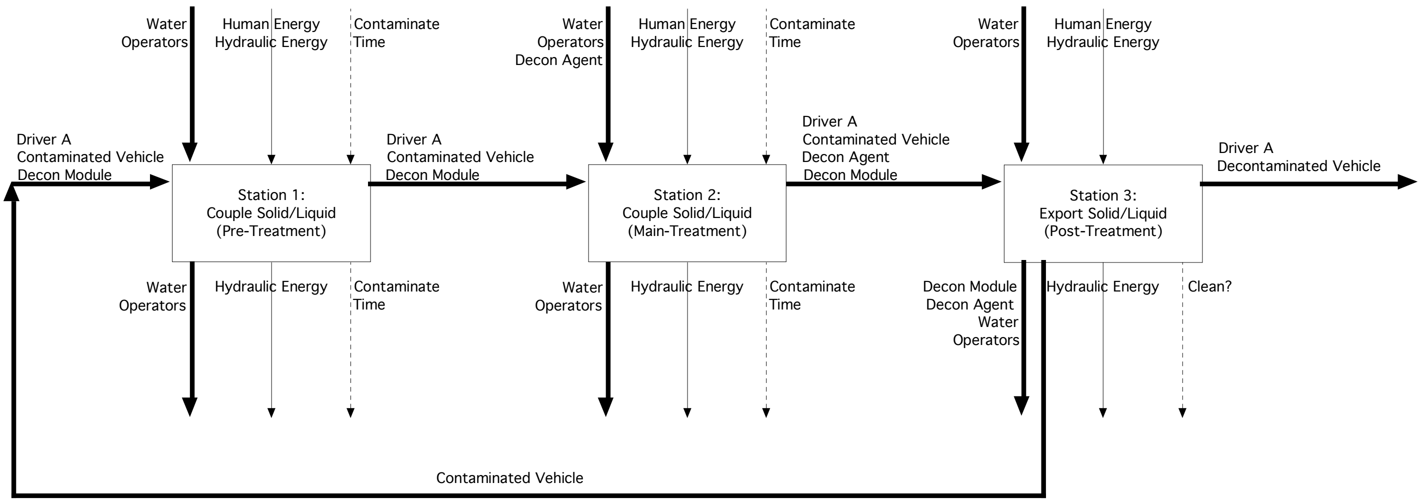

Figure 5: Entire black box process model for Kärcher TEP 90 decontamination system

Table 3: Mapping of tasks to associated requirements and input/output flows in step 2

Major task	Associated requirements	Input flows [type]	Output flows [type]
Pre-Treatment (Kärcher TEP 90 Station 1)	Increase efficiency	contaminated vehicle [M]; start time [S]	contaminated vehicle [M]; end time [S]
	Minimized risk of soldiers	human (potentially contaminated[M]	human [M]; human (driver) [M]
	Identification of potential uses of automation	human energy [E]; hydraulic energy [E];	hydraulic energy [E];

Step 3:
Utilizing the flows developed in step two, black box event models as stations are developed. Since the analyzed decontamination processes are pre-existing procedures, they are already decomposed into independent stations, which lends itself well to the process modeling methodology. As per the convention, flows between stations enter and exit through vertical sides, and flows unique to a station flow through horizontal sides. Figure 4 provides an example black box for station 1 of the Kärcher TEP 90 decontamination system.

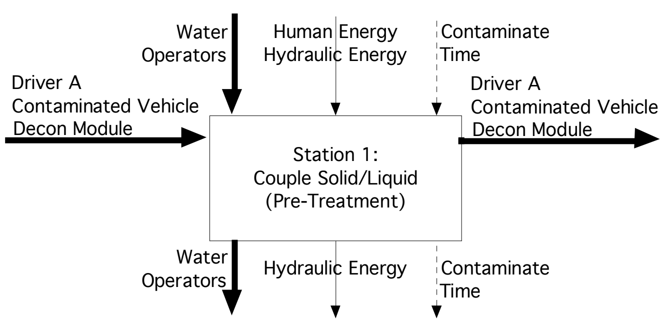

Figure 4: Station 1 black box model for Kärcher TEP 90 decontamination system

The overall process event of station 1 is to export solid/liquid mixture, which represents the Pre-Treatment phase where visible dirt is removed. The material, contaminated vehicle, flows separately through the station since it is required for station 2, Main-Treatment. Other flows like operators, water, and hydraulic energy that are not required for station 2 are separated and flow through the horizontal sides of the model.

Figure 5 provides the entire set of black box event models for the process model. For each black box event, there is flow between stations, flow unique to a station, and eventually system feedback from station 3 to station 1. The feedback loop is a result of the necessity to decontaminate equipment failing decontamination after a first pass. A unique situation is caused by the feedback. Station 3 has three unique material flows from its black box event model, a clean vehicle, if the vehicle passes inspection; a contaminated vehicle, if it fails; and the operators and wash system. Each of these three material flows are given a separate material flow since they are unique in purpose and destination.

Step 4:
The fourth step is to breakdown each black box event/station model into a more detailed subprocess event model. A subprocess model can be developed for each of the black box station models in DED, DTD, and Kärcher TEP 90. These subprocess models consist of all flow chains or tasks required to complete the high-level process event of each station. Figure 6 provides the subprocess model for station 1 Pre-Treatment phase of Kärcher TEP 90. The vehicle moving into the station is represented as import solid. Then the vehicle is brought into the proper position with guide solid. The water is represented by import hydraulic energy, and import liquid. These are brought to the contaminated vehicle via supply liquid and a guide hydraulic energy. The pressure washing subprocess event goes to an indicate time event that then links to the time line. There is a 7 minute time constraint for pressure washing. All visible contaminate/grime is separated from the vehicle. The still contaminated but visibly cleaner vehicle is exported with the export solid process event. The grime and contaminate are exported via an export solid-liquid mixture. Visible grime on the vehicle becomes a control signal with the event process import control signal.

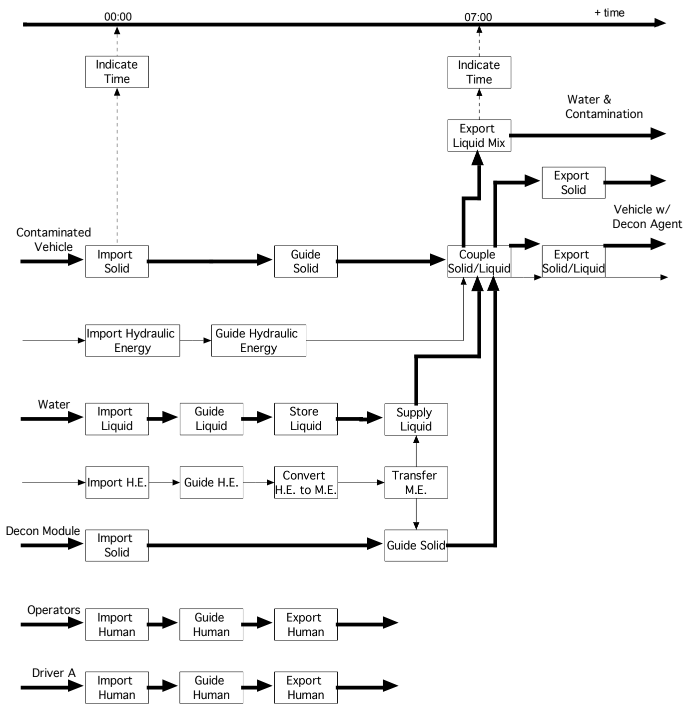

Figure 6: Station 1 process model from Kärcher TEP 90 decontamination system

Step 5:
The fifth step is to verify that all customer needs and process requirements have been addressed within the process model. Verification was performed by checking the input/output flows from each subprocess model to the mapped flows developed in step two. Failure to include all process requirements and customer needs would cause false returns in all further analysis of the process models.

5.3 Insights from the Process Model

Following the completion of the process model, analysis of the subprocess events can be performed to determine automation potential. To do this, the matrix methodology for determining product similarity is applied. Table 4 is the resultant station-process event similarity matrix for the three stations of the Kärcher TEP 90 decontamination system.

Table 4: Kärcher TEP 90 decontamination system product similarity matrix

	Pre-Treatment	Main-Treatment	Post-Treatment
Pre-Treatment	1	0.975	0.920
Main-Treatment	0.975	1	0.897
Post-Treatment	0.920	0.897	1

The product similarity matrix revealed a high level of similarity in process and function for all three stations of the Kärcher TEP 90 decontamination system. Therefore, it is anticipated that a single automation solution may be able to solve all of the identified processes and functionality. Performing the same analysis on the five stations of DED revealed a similar trend. It could be determined that station 1 and station 4 were completely similar and have a high potential for component streamlining, and in fact, all stations in the DED example have a significant amount of similarity. The similarity matrix for DED is provided as Table 5.

Table 5: DED station product similarity matrix

	Station 1	Station 2	Station 3	Station 4	Station 5
Station 1	1	0.742	0.693	1	0.720
Station 2	0.742	1	0.798	0.742	0.742
Station 3	0.693	0.798	1	0.693	0.748
Station 4	1	0.742	0.693	1	0.720
Station 5	0.72	0.742	0.748	0.720	1

Examining the similarities between stations and available automation processes identified other areas of potential automation and streamlining. As expected the equipment identified for potential streamlining closely resembled automated car or truck wash systems. It is the hope of the investigators that the US Army can utilize the findings of this study to modify the current NBC decontamination process making it safer for the soldiers, crews, and the environment.

6. CONCLUSIONS AND FUTURE WORK

The method proposed for process modeling has many improvements over current process or event planning and scheduling methodologies currently available. Via a newly added time line and time flow, process events can be mapped in a temporal domain, which allows for the scheduling benefits provided through Gantt and PERT charts. The utilization of functional modeling techniques and the Functional Basis provide rigid guidelines for clearer task and event modeling. Specified functions and flows maintain clarity through process events, increase efficiency, and ensure uniform results. This combination of features pulls together the best features of the Gantt and PERT charts, activity and workflow activity models, and functional modeling techniques to develop a simple yet effective process modeling technique.

Frequently, design projects focus on the formulation of a physical artifact, system, or subsystem. This approach, however, may not always be valid. In the case of a manually operated process that is to be automated, the focus must be expanded to model the actual process. Process modeling allows the designer to look at the individual tasks and identify anomalies that might otherwise be overlooked. In the case of the NBC decontamination procedure, station one and four appeared to be different processes with different tasks and goals, but when modeled using the process modeling techniques outlined in this paper, it was found that they were actually completely similar.

Future work will include further refinement and analysis of the NBC decontamination process and further testing of process modeling techniques. The NBC decontamination process models will be further refined. Further, task similarities will be investigated so as to develop a streamlined and possibly automated NBC decontamination procedure that reduces risk to decontamination crews, soldiers, and environment. Further refinement of the NBC decontamination procedure will allow for more opportunities to prove process modeling utilizing functional modeling techniques. Further testing of process modeling will investigate streamlining through more stringent temporal requirements and development of processes where specific tasks and events are not well defined.

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