Appendix D. Extended Methods

A. Literature search

The study began with an extensive search of the literature. Eligible studies included articles published between January 1, 1995 and January 1, 2008 and were restricted to peer-reviewed sources published in English. We included studies using qualitative, quantitative, and mixed methods. Literature matching search criteria but from non-peer reviewed sources was used as a source of suggestions for terms to refine our search criteria. Peer-reviewed conference proceedings were included in addition to peer-reviewed journals due to the emergent nature of workflow research. The two reviewers assessing the search results represented an engineering perspective (KMU) and a social sciences perspective (LLN).

The search began by selecting databases and search phrases. After a thorough examination of available databases, we included the following databases:

- ACM Digital Library[1]
- IEEE Xplore[2]
- International Bibliography of the Social Sciences (IBSS)[3]
- ISI Web of Science[4]
- PsycINFO[5]
- PubMed/Medline[6]
- Sociological Abstracts[7]

The selected databases covered a broad range of fields incorporating engineering, basic sciences, and social sciences. We pilot tested search terms across all of the selected databases with a goal of developing a common set of terms, limiting the search to title and abstract fields to focus on articles with a major focus on workflow or workflow-related topics. At each stage of refinement of search terms, multiple abstracts were examined to ensure the search terms retrieved articles matching our study goals. The final set of search terms used across all of the databases were:

> "work analysis" OR "work analyses" OR "work management" OR "work system" OR "work model" OR "work models" OR "work pattern" OR "work context" OR "work optimization" OR "healthcare work" OR "clinical work" OR "workflow analysis" OR "workflow management" OR "workflow system" OR "workflow management system" OR "workflow model" OR "workflow modeling" OR "workflow optimization" OR "clinical workflow" OR "efficient workflow" OR "clinical care delivery"

Information for all articles matching the search terms was retrieved, including title, abstract, date of publication, journal, database source, database unique identifier (when available), and authors. We then transferred the article information into a FileMaker® Pro 9 database developed specifically for this study. The FileMaker® database included rules to automatically exclude duplicate entries based on title, journal, and author matches.

B. FileMaker database

The broad nature of the review questions and the range of selected literature databases resulted in a large number of matching studies. We determined that managing the review of this large dataset required a software-based solution. Confronted with a tight timeline for review completion and limited software development resources, we explored the possibility of using off-the shelf software but were unable to locate a solution that addressed our needs. Several factors resulted in the selection of FileMaker Pro 9 as the rapid prototyping platform for the review database: support for multiple operating systems, built-in web publishing functionality, simplicity of database creation and maintenance, and ease of exporting structured data for further analysis. Built-in web publishing functionality in FileMaker resulted in easy centralization of the data store with distributed data entry. The minimal effort involved in creating a multi-user version of the database resulted in rapid design iteration, even with very limited software resources.

The final version of the FileMaker database assisted the researchers in efficiently and effectively managing the systematic literature review process. Data collection forms were incorporated into the FileMaker interface for each stage of the review. The interface supported concurrent review of abstracts by both reviewers while blinding each reviewer to inclusion/exclusion decisions of the other reviewer. The database collated article data (year of publication, title, abstract, authors, journal, etc) with review data (inclusion/exclusion status, data collected for each article), allowing preliminary analyses within FileMaker and later export to other data analysis tools, such as Excel and NVivo.

The FileMaker database and a later database version developed in mySQL are available for use by other researchers by contacting the corresponding author.

C. Review of identified articles

After establishing the corpus of review literature, two reviewers (KMU, LLN) pilot tested the abstract review process. Each reviewer independently evaluated 100 abstracts against the inclusion/exclusion criteria. Exclusion criteria categories included (Table A): focus on bioinformatics or basic science, focus on computer science or technology, focus on a medical condition, workflow was a minor part of study, and not peer reviewed.

Table A. Explanation of exclusion categories

Exclusion category	How articles matched search terms	Reason for exclusion
Focus on bioinformatics or basic sciences	Several scientific fields routinely use workflow-related terms to describe processes automated by equipment (ie processing sequences for biological samples)	Focus of literature review was on work performed by humans, not on equipment automation
Focus on computer science or technology	Several of the search terms referred both to work performed by humans and specific types of computer programs or other technology (ie technical design specifications for workflow management software)	Focus of literature review was on work performed by humans, not on computer programs unless used to facilitate human work activities
Focus on a medical condition	Several medical fields use workflow-related terminology to describe processes automated by equipment (ie a "radiology workflow" describing a equipment task sequence to obtain specific types of images) or to ergonomic aspects of manual work (ie occupational safety checklists related to repetitive stress injuries)	Focus of literature review was on work performed by humans, not on equipment automation or on musculoskeletal effects of work
Workflow was a minor part of the study	The search terms were applied to titles and abstracts and some articles that did not focus on workflow included the search terms in these fields	Target of the literature review was research that focused on workflow
Not peer reviewed	Some of the databases included non-peer reviewed material such as text books	Only peer reviewed literature was included in this review

The reviewers also excluded cognitive work analysis studies[8], concluding that these studies engaged a well-articulated toolset based in cognitive engineering that is more appropriate to evaluate separately. We modified the review forms in the FileMaker® database and reviewed exclusion criteria definitions in response to the pilot test. No systematic sources for pilot test inclusion/exclusion differences were identified. Both reviewers then independently evaluated abstracts for the full literature corpus. We assessed inter-rater agreement for the title and abstract review using Yule's Q[9], where

$$\text{Yule's Q} = \frac{[\text{Odd's Ratio} - 1]}{[\text{Odd's Ratio} + 1]}$$

Any article that either or both reviewers selected for inclusion was included in the next phase of review.

The full text of all included articles was retrieved. Both reviewers independently evaluated the full text articles for inclusion, using the criteria established during the abstract review. All articles included by either or both reviewers were included in the final phase of review. During the full-text review, we marked article references of interest, retrieved these additional referenced articles, and evaluated them for inclusion. Disagreements on inclusion status were resolved by consensus.

We developed and pilot-tested a form to standardize data collection for the included articles. The data collection form (see Appendix A Data Collection Form, available as an online data supplement at www.jamia.org) was integrated into the FileMaker database and included fields related to researcher perspective, article type, study design information, methods details, and dependent variables. We classified the type of article into five categories: Descriptive, Intervention, Theory, Viewpoint, and Literature Review. We allowed multiple selections for article type; for example, an article could be categorized as both Descriptive and Theory. Categories for study methods included: qualitative, quantitative, and mixed. Free-text fields were used to collect approaches to evaluation of the quality of study results. For researchers working in the positivist or objectivist research paradigm[10], evaluation of study result quality involves assessment of validity, or how closely measurements capture the goal variable, and reliability, or the reproducibility of the measurement[11]. For researchers working in the constructivist or naturalistic research paradigm[12], evaluation of study result quality involves assessment of confirmability, or how accurately the study results represent subject constructions of the data as

opposed to researcher constructions, and transferability, or how applicable the study findings are to other contexts[13]. We incorporated terminology on quality assessment from both paradigms to ensure capturing this data regardless of research paradigm. We collected data on dependent variables, or the phenomena being affected by workflow (i.e. efficiency, clinical outcomes, resource allocation), and categorized each specific dependent variable along the six IOM aims for improving the healthcare system: Safe, Effective, Patient-Centered, Timely, Efficient, and Equitable.

The data collection form included an option to select the "Other" category for several fields: Domain, Type of Article, Researcher Perspective, Level of Focus, Study Subjects, Length of Study, Type of Methods, Specific Methods Used, and Steps to Ensure Reliability and Validity. A selection of "Other" for any of these categories required the reviewer to enter a free-text explanation. After concluding data collection, the researchers reviewed the free-text entries for each data category and organized these responses into logical groups. For example, for the Study Subjects data field, responses including airport security, military personnel, criminal justice workers, emergency responders, and power plan operators were grouped into the category "Military and public infrastructure personnel". Researchers discussed all categories for all data fields extensively to ensure consensus on categorization. The categorization process for fields with "Other" options results in more categories for each data field than listed on the data collection form.

During the pilot phase of abstract review, we identified widely varying definitions of workflow across studies and added a free-text field on the data collection form to capture these differing definitions. While some articles included a coherent statement describing the researchers' definition of the workflow concept, many articles left this definition up to the reader to derive. In cases where articles provided a clear definition of workflow, we recorded this definition. In cases where the workflow definition in the article was not clearly stated, we considered both the content and context of the article while deriving a workflow definition for the article. We considered multiple axes when examining article context such as journal, research field (i.e., engineering, psychology, anthropology, computer science, etc), theoretical constructs described in the article, scope of study, and research setting. As a result of the data collection process, the definition of workflow field includes both stated and derived definitions.

D. Data analysis

The initial analysis focused on descriptive statistics of key variables for the included article corpus and examining key variables for interactions, such as methodology selection trends over time. The wide-ranging review results prompted inductive analyses of text-based data fields including definitions of workflow and dependent variable selection. NVivo qualitative analysis software[14] and Microsoft Excel were used to facilitate the inductive analysis.

Applying techniques developed in our previous qualitative research[15, 16], we pursued two distinct but complementary strategies for identifying patterns in the workflow definition data (Figure A). The first strategy focused on grouping workflow definitions based on researcher perspectives towards workflow, including methodological and motivational orientations. We combined the stated and derived workflow definitions with the researcher perspective data and then inductively analyzed this information for patterns. In the second strategy, we extracted key phrases based on content and context from each workflow definition. We then analyzed the key phrases and workflow definitions to identify common components that played roles in defining workflow across research fields. We grouped these components into categories through an analysis grounded in the data and examined inter-category relationships. Information regarding the content and context of each article informed both analysis strategies. The analyses focused on identifying cross-disciplinary commonalities in the study of workflow, while still maintaining awareness of discipline-specific concepts.

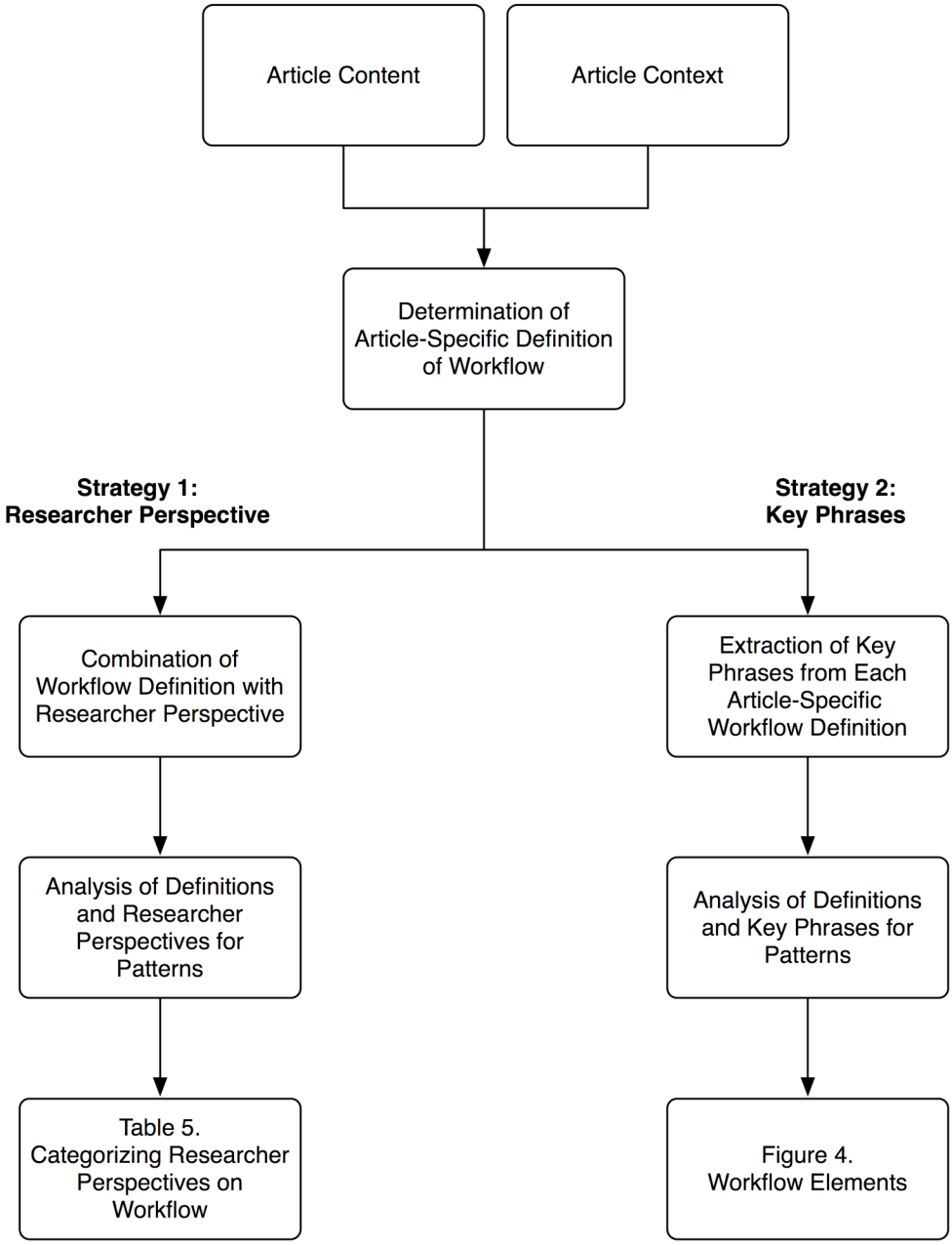

Figure A. Workflow Definitions Analysis Process

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