International Journal of Industrial Engineering, 16(4), 331-343, 2009.

DEVELOPING MTM MODIFIERS FOR FINGER DISABILITIES

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Disability and rehabilitation research and practices have traditionally aimed at creating self-sufficiency, along with equal opportunities among individuals with disabilities. The need and benefits of such initiatives are important, particularly with the increasing influx of disabled individuals into the work force. It has become necessary focus on rehabilitating the disabled and special populations at the work place and to do it in an economically viable manner without adversely affecting productivity. Work standards have traditionally served as a reliable means of establishing consistent data on activity and job completion times for comparative, control, or remuneration purposes. Yet with the changing demographics, it is necessary that the standard times and the work measurement data developed for healthy population is tailored to fit the requirements of special populations. This experimental study aimed at providing modifiers to elemental tasks when performed by individuals with finger disabilities. These modifiers should provide the management with information necessary to integrate the disabled into the workforce. The study reported here simulated three kinds of finger disabilities while performing various assembly-disassembly tasks. Results indicated that there was a significant increase in performance times with disabilities, both at the elemental level and at the higher level. While the elemental time with disabilities increased by as much as one-hundred fifty percent, overall times with disabilities increased by as much as one hundred eight percent. Based on the results of the experimental simulation, generalized modifiers for PMTS tasks were developed in order to estimate performance times for individuals with finger disabilities.

Significance: PMTS modifiers are developed to accommodate individuals with finger disabilities in the work place.

Keywords: Finger disability, dexterity tasks, work measurement, MTM, PMTS, elemental task, time standards.

(Received 27 June 2007; Accepted in revised form 26 June 2009)

1. INTRODUCTION

As discussed by Subramanian and Mital (2007), disabilities among people are common in communities around the world. Despite variations in the disabled populations, there are trends that are common to most countries in terms of increasing disability prevalence rates and continued influx of partially disabled population into the work force. With improvements in science and technology, the life expectancy has increased. Associated with this increase in life expectancy are increases within the prevalence of disabilities and related costs. Current work trends portend increasing challenges for accommodating the disabled workers and employers who undertake such ventures.

Figure 1 shows the prevalence of disability among men and women in the United States over the past two decades. According to the US Census Bureau (2006), there are thirty-seven and half million (fourteen percent of the US population) disabled Americans over the age of five. This does not include individuals institutionalized and in health care and nursing homes. Approximately forty-two percent of all disabled men between ages of twenty-one and sixty-four are employed in some form or the other. A similar estimate for women gives thirty-four percent employed. An estimated eight percent of civilian non-institutionalized people aged between 18 years of age and 64 years of age in the United States reported a work limitation. These disability statistics, however, do not include children under eighteen and adults over sixty-five years of age.

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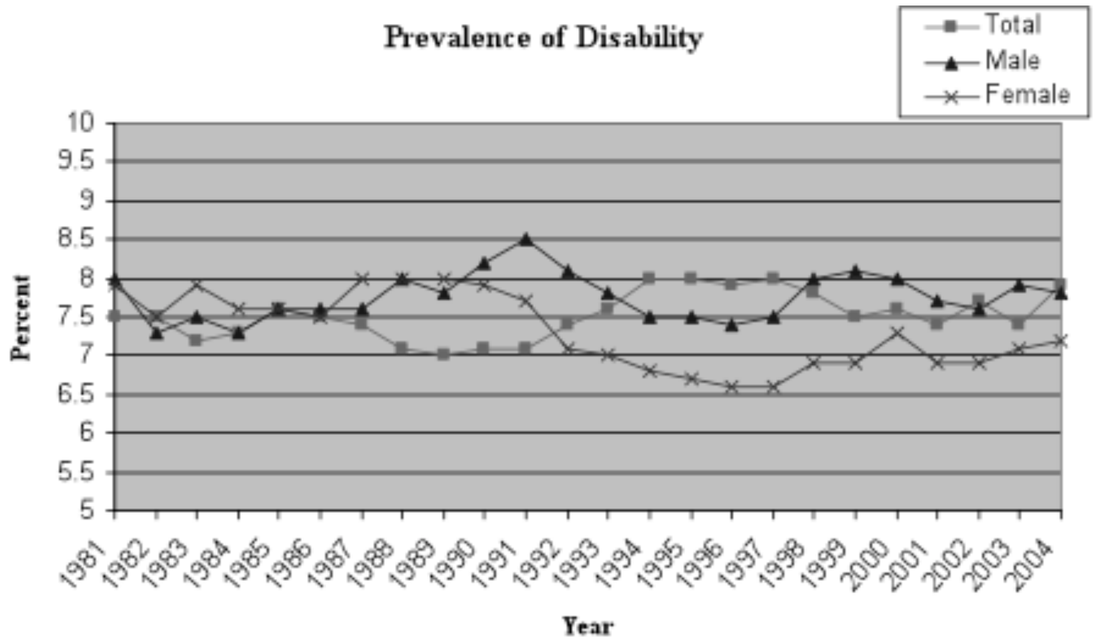

Figure 1. The percentage of men, women and the total, aged 18-64 who reported a work limitation in the United States from 1981 – 2004.

Table 1 summarizes the Bureau of Labor Statistics (2009) data on the total number of non-fatal injuries in the work place and the incidence rates for the upper extremities. As evidence shows injuries to fingers are most prevalent, ranging from approximately thirty-five to thirty-nine percent of the total upper extremity injuries. Given the high proportion of injuries to fingers and the fact that fingers are the most dexterous part of the human body, there is a definite need to accommodate individuals with finger disabilities in the workplace. The need for providing accommodation is further emphasized by the Acts such as the Americans with Disabilities Act (1990) and Workforce Investment Act (1998). Besides legal requirements, it makes economic sense to gainfully employ the disabled (Subramanian and Mital, 2007).

Table 1. Number of non-fatal occupational injuries classified by the part of body affected (Bureau of Labor Statistics, 2009)

	Total Number (Incidence rates)				
	2003	2004	2005	2006	2007
All private Industry	1315920 (150)	1259320 (141.3)	1234680 (135.7)	1183500 (127.8)	1158870 (122.2)
Wrist	65280 (7.4)	58510 (6.6)	56250 (6.2)	48810 (5.3)	51620 (5.4)
Hand (except) fingers	51120 (5.8)	50190 (5.6)	47020 (5.2)	49480 (5.3)	47920 (5.1)
fingers	106370 (12.1)	107860 (12.1)	111090 (12.2)	106050 (11.5)	101650 (10.7)
All Upper extremities	298530 (34)	290460 (32.6)	284750 (31.3)	274180 (29.6)	269240 (28.4)

As discussed in the review by Subramanian and Mital (2007), the existing Pre-Determined Motion Time Systems (PMTS) do not generate work standards for people with disabilities. In order to accommodate the disabled in the workplace gainfully, employers must know how much work a disabled person can perform in a day, how much time would a disabled person take to complete the work cycle, how to determine the remuneration for the disabled, and what impact would the integration of the disabled individual have on the organizational productivity. The answers to all these questions require modifications of existing PMTSs. In this paper, the authors discuss the modifications of MTM elemental times for individuals with finger disabilities.

2. EXPERIMENTAL SIMULATION

The primary objective of this work was to develop modifiers for MTM - PMTS so that time standards for routine tasks performed by individuals with finger disabilities could be developed. The tasks simulated various types of simple assembly and disassembly activities.

2.1 The Disability

The disabilities simulated were specific and were defined as follows: (1) the loss of four fingers in the primary (preferred) hand (condition-D01); (2) the loss of the thumb in the non-preferred hand (condition-D02); and (3) the loss of four fingers in the primary (preferred) hand and the loss of thumb in the non-preferred hand (condition-D03). The disabilities were simulated by the use of special gloves (Figure 2). Figures 3, 4, and 5 show the three disabilities. The design of the gloves was such that, when donned, the movement of the thumb or the four fingers would be restricted to simulate the disability. Care was taken to ensure that constraint on fingers or the thumb did not restrict the blood flow. The gloves were tightened such that the movement was prevented while experiencing no discomfort. Individuals participating in the study were repeatedly asked to indicate if there was any discomfort. The glove material was thin and did not hinder intended movement or performance.


Figure 2. Gloves designed to simulate the disabilities

Figure 3. Loss of the use of four fingers in the preferred hand

Figure 4. Loss of the use of thumb in the non-preferred hand

Figure 5. Loss of the four fingers in the preferred hand and the thumb in the non-preferred hand

In addition to the three simulated disabilities, participants also performed the tasks without any finger restrictions (condition-D00). This unrestricted performance was considered the control condition against which all other performances (with simulated disabilities) were compared.

2.2 Study Participants

Twenty volunteers, recruited locally, performed the simulated tasks with and without the specified finger disabilities. All participants were healthy, with no physical ailment or any medication history. Their age ranged from twenty-one and thirty-two years. During the experiment, individuals wore comfortable clothes. They used an adjustable height chair and were instructed that they could stop their participation at any time if they felt any discomfort or were not ready to perform the specified tasks.

2.3 The Experiment

The dexterity tasks were performed using the basic Hand-Tool Dexterity Test equipment (Figure 6). This equipment allowed measurement of time it took individuals to perform Nut and Bolts assembly or disassembly using common screwdrivers and wrenches. The task required placing the bolts, with the heads of the bolts on the preferred hand side, in the holes on the frame upright using common wrenches and screwdrivers. Said tools were placed at the center of the frame between the uprights. For disassembly, the nuts and bolts were loosely tightened.

Figure 6. The hand tool dexterity equipment

Sequence of assembly and disassembly tasks is shown in Figures 7 and 8, respectively. The experimental protocol was demonstrated to each participant. The protocol required that nuts and bolts not be tightened excessively. Each participant practiced the assembly-disassembly sequence until they felt comfortable with the sequence and the learning effect was over. This protocol was repeated for each simulated disability and the control condition (no disability). Entire task performance was videotaped for each condition.

Each participant performed three different assembly tasks and three different disassembly tasks for the control condition and the three disability conditions. Throughout all of these tasks, each participant performed twenty-four different task-disability combinations (Figures 7 and 8). The order of performance of these 24 combinations was randomized and adequate rest was provided between conditions to avoid fatigue. Figure 9 shows the schematic layout of the task setup.

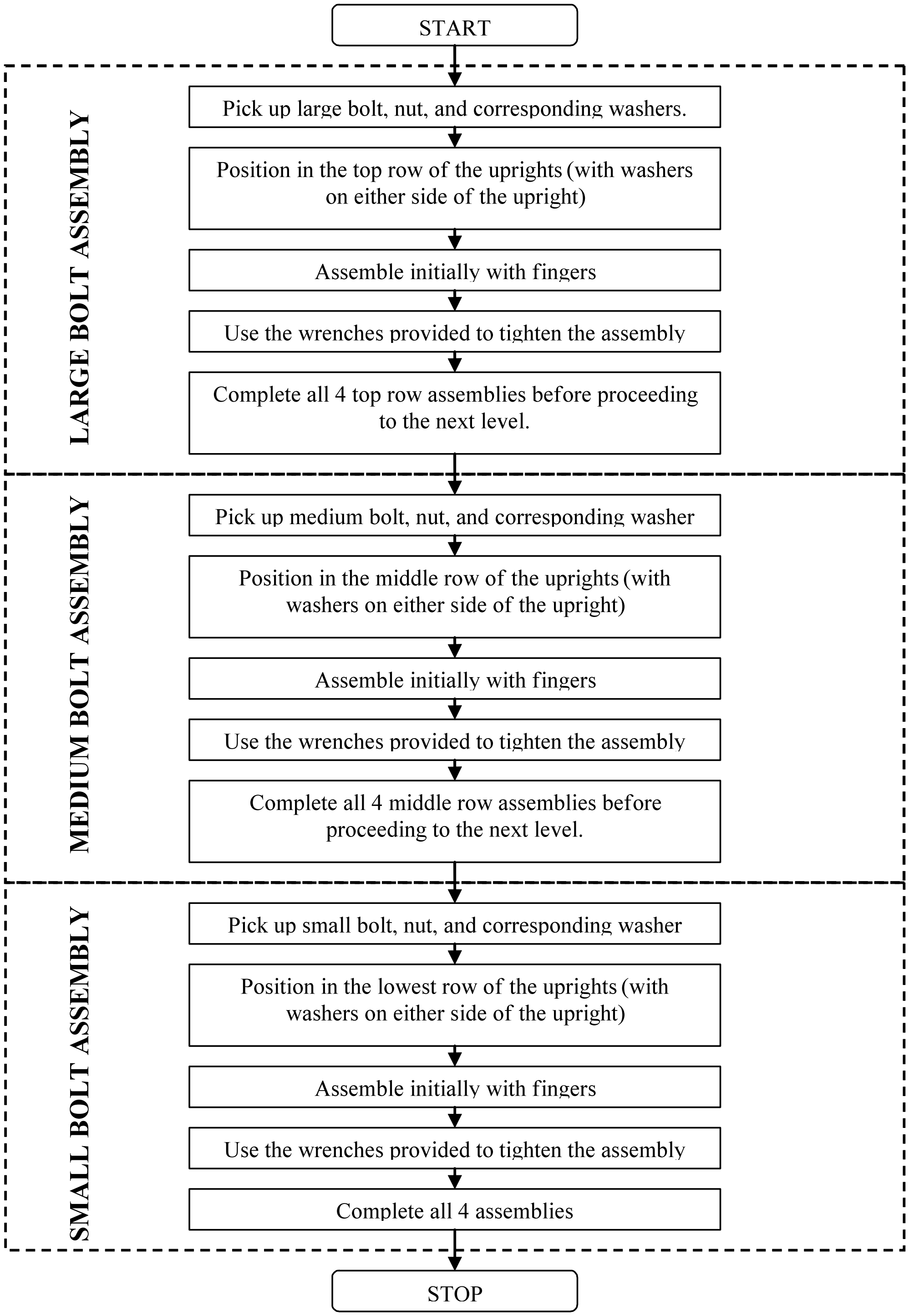

Figure 7. Typical sequence of assembly simulated for dexterity tasks

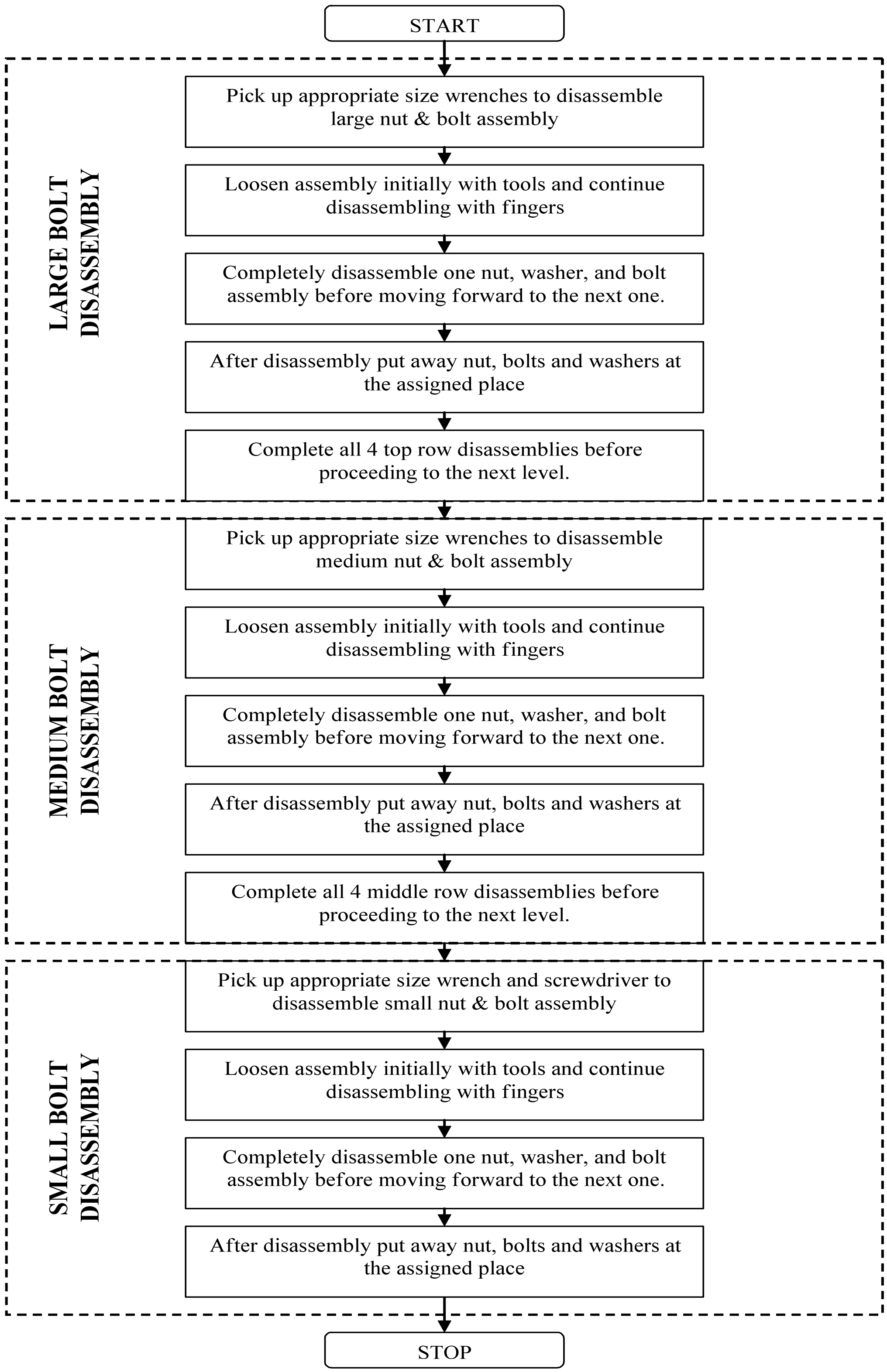

Figure 8. Typical sequence of disassembly simulated for dexterity tasks

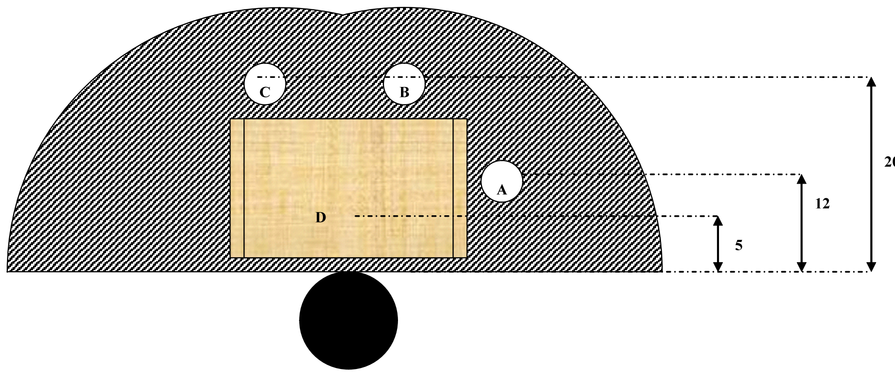

Figure 9. Schematic layout of the setup for dexterity tasks

2.4 Data Analysis

The tasks shown in Figures 7 and 8 were broken down into MTM elements. Table 2 shows the list of MTM elements that were timed in the task analysis. The tasks video recordings were subjected to frame-by-frame analysis using a large screen computer and Cyberlink Power DVD software. The speed of the video film was 30Hz. The start and end points for each element was controlled to be within four video frames. Time (in frames) between successive elements was not lost, or duplicated, as long as the elements were contiguous. These precise start and end points for each element timed are listed in Table 3. The elemental times computed from this video analysis were compared with the standard MTM-1 elemental times in order to generate appropriate multipliers (correction factor) for the specific disability condition.

Table 2. List of MTM Elements

Dexterity	
Assembly	**Disassembly**
Large assembly	Large disassembly
Reach large N-B	Reach large tools
Grasp large N-B	Release large tools
Move large N-B	Move large N-B
Position large N-B	Release large N-B
Reach large tools	
Grasp large tools	
Move large tools	
Release large tools	
Medium assembly	Medium disassembly
Reach medium N-B	Reach medium tools
Grasp medium N-B	Release medium tools
Move medium N-B	Move medium N-B
Position medium N-B	Release medium N-B
Reach medium tools	
Grasp medium tools	
Move medium tools	
Release medium tools	
Small assembly	Small disassembly
Reach small N-B	Reach small tools
Grasp small N-B	Release small tools
Move small N-B	Move small N-B
Position small N-B	Release small N-B
Reach small tools	
Grasp small tools	
Move small tools	
Release small tools	

Table 3. Descriptions of start and end points for MTM Elements

Activity	Start Point	End Point
Assembly (Large, Medium, Small)	First limb movement to reach for first item (nut, bolt, or washer)	Last touch or release of the tools after completing the assembly operation
Disassembly (Large, Medium, Small)	First limb movement to reach for the tools	Last touch or release of the nuts, bolts, or washer after completing the disassembly operation
Reach N-B (Large, Medium, Small)	First limb movement to reach for the nut/bolt/washer	Limbs completely extended and reached the location of the nut/bolt/washer
Grasp N-B (Large, Medium, Small)	Limbs reach the location of nut/bolt/washer or end of reach NB activity (if no delays present)	Limbs begin to move away/retract after picking up the nut/bolt/washer
Move N-B (Large, Medium, Small)	Limbs begin to move away/retract after picking up nut/bolt/washer or end of the grasp NB activity (in no delays are present)	Limbs reach the location of assembly or limbs stop moving
Position N-B (Large, Medium, Small)	Limbs reach the location of assembly or end of the move NB activity (if no delays are present)	Bolt-washer combination passes through the hole ready for the washer-nut to be assembled
Assemble NB-hands (L,M,S)	Subject starts to assemble the washer-nut to the bolt or end of the position NB activity (if no delays are present)	Subjects begins to move limbs to reach for the tools after tightening the nut-bolt with hands
Reach tools (Large, Medium, Small)	Limbs start to move away from assembly location or end of the assemble NB hands activity (if no delays are present)	Limbs stop moving after reaching the location of the tools
Grasp tools (Large, Medium, Small)	Limbs start moving after reaching the location of the tools or end of the reach tools activity (if no delays are present)	Limbs begin to move away/retract after picking up the tools
Move tools (Large, Medium, Small)	Limbs begin to move away/retract after picking up the tools or end of the grasp tools activity (if no delays are present)	Limbs reach the location of assembly or limbs stop moving
Assemble NB-tools (L,M,S)	Limbs reach the location of assembly or limbs stop moving	Limbs move away from the assembly after tightening
Release tools (Large, Medium, Small)	Limbs have stopped moving after reaching the drop point for the tools	Last touch of the tools or hands start to retract after leaving the tools
Disassemble NB-tools (L,M,S)	Limbs reach the location of assembly or limbs stop moving	Limbs move away from the assembly after loosening the nut-bolt assembly
Disassemble NB-hands (L,M,S)	Limbs reach the location of assembly or limbs stop moving	Limbs move away from the wooden uprights after completely dismantling the nut-bolt assembly
Release N-B (Large, Medium, Small)	Limbs have stopped moving after reaching the drop point for the nuts/washer/bolt	Last touch of the nuts/bolts/washer or hands start to retract after leaving the nut/bolt/washer

3. RESULTS

The elemental time data for each experimental condition – performance with the three simulated finger disabilities– was compared with the control condition elemental times. This comparison is shown in Table 4.

Table 4. Percentage variation for each disability over the control scenario

Task	Elemental task	D01	D02	D03
Large Bolt Assembly	Reach large N-B	1.26%	1.26%	1.26%
	Grasp large N-B	18.22%	15.34%	48.31%
	Move large N-B	0.71%	0.71%	0.71%
	Position large N-B	2.62%	1.15%	7.18%
	Reach large tools	1.37%	1.37%	1.37%
	Grasp large tools	123.80%	89.67%	148.57%
	Move large tools	1.02%	1.02%	1.02%
	Release large-tools	1.54%	1.54%	1.54%
Large Bolt Disassembly	Reach medium N-B	2.89%	2.89%	2.89%
	Grasp medium N-B	0.66%	0.66%	0.66%
	Move medium N-B	2.39%	2.39%	2.39%
	Position medium N-B	3.19%	3.19%	3.19%
Medium Bolt Assembly	Reach medium tools	0.95%	0.95%	0.95%
	Grasp medium tools	16.17%	12.63%	48.81%
	Move medium tools	3.04%	3.04%	3.04%
	Release medium-tools	6.46%	3.36%	57.87%
	Reach small N-B	1.87%	1.87%	1.87%
	Grasp small N-B	38.00%	19.55%	55.61%
	Move small N-B	3.38%	3.38%	3.38%
	Position small N-B	0.87%	0.87%	0.87%
Medium Bolt Disassembly	Reach small tools	1.38%	1.38%	1.38%
	Grasp small tools	5.31%	5.31%	5.31%
	Move small tools	1.12%	1.12%	1.12%
	Release small-tools	1.95%	1.95%	1.95%
Small Bolt Assembly	Reach large tools	2.50%	2.50%	2.50%
	Release large-tools	18.45%	13.67%	75.88%
	Move large N-B	2.76%	2.76%	2.76%
	Release large N-B	10.67%	5.10%	75.80%
	Reach medium tools	2.57%	2.57%	2.57%
	Release medium-tools	61.43%	125.88%	85.51%
	Move medium N-B	0.83%	0.83%	0.83%
	Release medium N-B	4.51%	4.51%	4.51%
Small Bolt Disassembly	Reach small tools	1.23%	1.23%	1.23%
	Release small-tools	0.32%	0.32%	0.32%
	Move small N-B	0.25%	0.25%	0.25%
	Release small N-B	1.53%	1.53%	1.53%

As shown in Table 4, most elemental times for the disability conditions took significantly longer to perform than performing under the control condition ($\alpha < 0.05$). The exceptions were elements for reach and move ($\alpha \geq 0.10$).

Since times for elements such as grasp, release and position, were significantly longer for disability conditions, using MTM-1 for computing cycle times for assembly-disassembly tasks performed by individuals with finger disabilities would be inaccurate and provide false expectations for a day's output. Accurate determination of work-cycle times requires that MTM-1 times be modified for the disabled. This was accomplished by comparing Table 4 variations with MTM-1 times (Table 5). The comparison provides appropriate multiplier (correction factor) for each element in order to estimate times for the disability conditions. These multipliers are given in Tables 6 through 8.

Table 5. Elemental times based on MTM-1

Task	Element	PMTS Code	TMUs	Leveled Time (secs)	Standard time (secs)
Large Bolt Assembly	Reach (NB)	R12B	12.9	0.464	0.534
	Grasp (NB)	G1A	2	0.072	0.083
	Move (NB)	M12A	12.9	0.464	0.534
	Position (NB)	P1SE	5.6	0.202	0.232
	Reach (Tools)	R5B	7.8	0.281	0.323
	Grasp (Tools)	G1A	2	0.072	0.083
	Move (Tools)	M5A	7.3	0.263	0.302
	Release (Tools)	RL1	2	0.072	0.083
Medium Bolt Assembly	Reach (NB)	R20B	18.6	0.670	0.770
	Grasp (NB)	G1C2	8.7	0.313	0.360
	Move (NB)	M10A	11.3	0.407	0.468
	Position (NB)	P1SE	5.6	0.202	0.232
	Reach (Tools)	R5B	7.8	0.281	0.323
	Grasp (Tools)	G1A	2	0.072	0.083
	Move (Tools)	M5A	7.3	0.263	0.302
	Release (Tools)	RL1	2	0.072	0.083
Small Bolt Assembly	Reach (NB)	R20B	18.6	0.670	0.770
	Grasp (NB)	G1C3	10.8	0.389	0.447
	Move (NB)	M10A	11.3	0.407	0.468
	Position (NB)	P1SD	11.2	0.403	0.464
	Reach (Tools)	R5B	7.8	0.281	0.323
	Grasp (Tools)	G1A	2	0.072	0.083
	Move (Tools)	M5A	7.3	0.263	0.302
	Release (Tools)	RL1	2	0.072	0.083
Large Bolt Disassembly	Reach (Tools)	R5B	7.8	0.281	0.323
	Release (Tools)	RL1	2	0.072	0.083
	Move (NB)	M10A	11.3	0.407	0.468
	Release (NB)	RL1	2	0.072	0.083
Medium Bolt Disassembly	Reach (Tools)	R5B	7.8	0.281	0.323
	Release (Tools)	RL1	2	0.072	0.083
	Move (NB)	M10A	11.3	0.407	0.468
	Release (NB)	RL1	2	0.072	0.083
Small Bolt Disassembly	Reach (Tools)	R5B	7.8	0.281	0.323
	Release (Tools)	RL1	2	0.072	0.083
	Move (NB)	M10A	11.3	0.407	0.468
	Release (NB)	RL1	2	0.072	0.083

Table 6. Correction factors and modified standard time for finger disability conditions for the Large bolt tasks

	ELEMENT	PMTS Code	Modifier (D01)	Modified PMTS D01 (secs)	Modifier (D02)	Modified PMTS D02 (secs)	Modifier (D03)	Modified PMTS D03 (secs)
Large Bolt Assembly	Grasp large N-B	G1A	1.18	0.098	1.15	0.096	1.48	0.123
	Position large N-B	P1SE	1.03	0.238	1.01	0.235	1.07	0.249
	Grasp large tools	G1A	2.24	0.186	1.9	0.157	2.49	0.206
	Release large-tools	RL1	1.02	0.084	1.02	0.084	1.02	0.084
Large Bolt Disassembly	Release large N-B	RL1	1.03	0.086	1.03	0.086	1.03	0.086

Table 7. Correction factors and modified standard time for finger disability conditions for the Medium bolt tasks

	ELEMENT	PMTS Code	Modifier (D01)	Modified PMTS D01 (secs)	Modifier (D02)	Modified PMTS D02 (secs)	Modifier (D03)	Modified PMTS D03 (secs)
Medium Bolt Assembly	Grasp medium N-B	G1C2	1.16	0.418	1.13	0.405	1.49	0.536
	Position medium N-B	P1SE	1.06	0.247	1.03	0.24	1.58	0.366
	Grasp medium tools	G1A	1.38	0.115	1.2	0.099	1.56	0.129
	Release medium-tools	RL1	1.01	0.084	1.01	0.084	1.01	0.084
Medium Bolt Disassembly	Release medium N-B	RL1	1.02	0.085	1.02	0.085	1.02	0.085

Table 8. Correction factors and modified standard time for finger disability conditions for the small bolt tasks

	ELEMENT	PMTS Code	Modifier (D01)	Modified PMTS D01 (secs)	Modifier (D02)	Modified PMTS D02 (secs)	Modifier (D03)	Modified PMTS D03 (secs)
Small Bolt Assembly	Grasp small N-B	G1C3	1.18	0.529	1.14	0.508	1.76	0.786
	Position small N-B	P1SD	1.11	0.514	1.05	0.488	1.76	0.816
	Grasp small tools	G1A	1.61	0.134	2.26	0.187	1.86	0.154
	Release small-tools	RL1	1.05	0.087	1.05	0.087	1.05	0.087
Small Bolt Disassembly	Release small N-B	RL1	1.02	0.084	1.02	0.084	1.02	0.084

4. CONCLUDING REMARKS

The overall objective of this work was to understand the influence of finger disabilities on work standards derived from MTM-PMTS. The results clearly show that finger disabilities increase cycle times significantly – elemental times increased by as much as one-hundred fifty percent while the overall cycle times increased by as much as one hundred eight percent. Furthermore, the type of finger disability influences the cycle time. Thus, using MTM-PMTS without any modification in elemental times would lead to erroneous work standards for individuals with finger disabilities. In order to provide more accurate time standards, the authors have developed and provided correction factors for some MTM-1 elements. These correction factors are applicable for estimating cycle times for manual assembly-disassembly tasks performed by individuals with pervasive finger disabilities.

Having established that disabilities affect work standards, in the future studies need to be broadened to include other tasks and other disabilities. However, prior to broadening the scope of the study the correction factors developed in this paper need to be verified. It should be noted that there are a wide variety of tasks as well as disabilities. The selection of disabilities in future studies should be based on the Bureau of Labor Statistics injury data. The selection of the tasks to be studied, on the other hand, should be based on a survey of tasks.

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BIOGRAPHICAL SKETCH

Anand Subramanian is a Senior Managing Engineer at JFAssociates, Inc. based in the Washington, DC area. Dr. Subramanian has a Doctoral and Masters Degree in Industrial Engineering from the University of Cincinnati, Ohio. His areas of specialty include time and motion studies, ergonomic evaluations, economic analyses, facilities planning, and warehouse design. He is co-author of a number of national and international journal publications and has made presentations at a number of prestigious Industrial Engineering and Ergonomic conferences.

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