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The Use of Thermal Capacity in Measuring the Effectiveness of Meals on Wheels Transport Containers

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Abstract

The Meals on Wheels (MOW) program is designed to help combat hunger in persons needing assistance. MOW has a duty not only to provide food but also to ensure that it reaches eligible clients safely. Given the population that MOW serves, transporting food safely takes on increased importance. This experiment focused on the major food safety issue of maintaining temperature integrity through the use of transport containers. For containers that did not contain electric heating elements, several factors influenced how fast the food temperature fell. Those factors included the U-value and size of the container as well as how many meals were in the container. As predicted, the smaller the U-value, the longer it took the temperature to fall. Larger containers did better at maintaining food temperatures, provided they were fully loaded. In general, fully loaded small and medium containers were better at maintaining food temperatures than larger containers loaded with the same number of meals.

Keywords

Meals on Wheels, Transportation, Thermal Capacity, MOW, Food Safety, Food Tempature, Food Handling

Cover Page Footnote

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By Lionel Thomas, Jr., Douglas Nelson, Barbara Almanza and Margaret Binkley

The Meals on Wheels (MOW) program is designed to help combat hunger in persons needing assistance. MOW has a duty not only to provide food but also to ensure that it reaches eligible clients safely. Given the population that MOW serves, transporting food safely takes on increased importance. This experiment focused on the major food safety issue of maintaining temperature integrity through the use of transport containers. For containers that did not contain electric heating elements, several factors influenced how fast the food temperature fell. Those factors included the U-value and size of the container as well as how many meals were in the container. As predicted, the smaller the U-value, the longer it took the temperature to fall. Larger containers did better at maintaining food temperatures, provided they were fully loaded. In general, fully loaded small and medium containers were better at maintaining food temperatures than larger containers loaded with the same number of meals.

INTRODUCTION

The ability to acquire and prepare nutritious, appealing meals; eat independently; dine in an environment that promotes proper caloric intake; and receive dietary assistance contributes to an adequate diet for elderly Americans (Payette & Shatenstein, 2005). Payette and Shatenstein affirmed that both individual and collective determinants are influential in motivating healthy aging in older Americans. Individual determinants that motivate dietary practices include demographic, physiological, health, and lifestyle practice stimuli. Collective determinants include access to information, nutritious food, healthy eating communication, social support, and community-based food delivery services, such as those provided by Meals on Wheels (MOW).

MOW is designed to help combat hunger and poor diets for the homebound, disabled, and frail, as well as individuals at risk socially, physically, nutritionally, and economically (Johnson & Fischer, 2004; Meals on Wheels Inc. of Tarrant County, 2004; Wellman & Kamp, 2004). The individuals served by this program have no means of receiving regular nutritional meals. Federal nutrition programs for the elderly provide more than 250 million congregate and home-delivered meals annually (Gollub & Weddle, 2004; Johnson & Fischer, 2004; Wellman & Kamp, 2004). The program typically provides five midday meals weekly for about three million qualified adults (Gollub & Weddle, 2004; Johnson & Fischer, 2004; Wellman & Kamp, 2004).

MOW is important because a large proportion of the elderly population in the United States is not consuming a balanced diet required to maintain good health (Connor, 1999). According to the Centers for Disease Control (CDC), a great deal of the illness and disability in older adults stems from detrimental behaviors, such as poor nutrition and the lack of physical activity (Lang, Moore, Harris, & Anderson, 2005). Many of the complications associated with aging can be improved through good nutrition (Holmes, 2006; Johnson & Fischer, 2004; Wellman, 2004).

Poor diet can contribute to frailty, functional limitations, loss of muscle mass, metabolic abnormalities, and diminished immunity (Payette & Shatenstein). Elderly persons also suffer from a number of the following complications that decrease their appetite and food intake: (1) a lessened ability to taste, smell, and digest food, affecting food selection (Johnson & Fischer, 2004; Schiffman, 1997; Schiffman & Graham, 2000); (2) chronic health problems (Holmes, 2006; Johnson & Fischer, 2004; Wellman, 2004); (3) slower gastrointestinal function, such that the stomachs of older persons release food more slowly into the intestines, leading to longer sensations of satiety and reduced energy intake (Johnson & Fischer, 2004); (4) medications that may adversely affect their immune system (Winkler, Garg, Mekayarajjananonth, Bakaeen, & Khan, 1999); (5) a reduction of appetite, sensory perception, and thirst sensation (Poehlman & Toth, 1996); (6) chewing problems (Brodeur, Laurin, Vallée, & Lachapelle, 1993); and (7) cognitive decline (Morely, 2001; Phillips, Bretheron, Johnston, & Gray, 1991; Schiffman, 1997; Volkert, 2005). MOW meals are intended to provide one-third of the daily caloric intake or recommended dietary allowance; however, studies have shown that clients' meals actually account for at least half of the food intake for the day (Wellman & Kamp, 2004).

Equally as important as providing a nutritious meal to elderly individuals is ensuring their meals are safe to eat. According to the US Food and Drug Administration (FDA), failure to hold food at the proper temperature is one of the five most common factors responsible for foodborne illness (US Food and Drug Administration Center for Food Safety and Applied Nutrition, 2005). Prevention of foodborne illness takes on an increased emphasis because the majority of the clients served are elderly individuals whose bodies have a diminished ability to combat illness. MOW operations bear the responsibility to protect their high-risk clients from harm by maintaining proper food- safety procedures throughout the flow of food service (Bertagnoli, 1996). This means that they must ensure that food stays out of the temperature range conducive to bacterial growth (temperature danger zone): 41°F (6°C) to 135°F

(57°C). The FDA mandates that hot food be kept above 135°F (57°C) and cold food be kept below 41°F (6°C) throughout the service process. If a hot food item is below 135°F (57°C) for a period of four hours, the item is to be discarded because of the increased potential for the rapid growth of bacteria (US Food and Drug Administration Center for Food Safety and Applied Nutrition). While the four-hour limit is recommended by the FDA, some states have adopted more stringent requirements: The New York State Department of Health Sanitation Code recommends holding potentially hazardous foods no longer than two hours in the temperature danger zone before discarding (Kraak, 1995).

Because of elders' susceptibility to foodborne illness, MOW must maintain food temperature during transportation from facility to client. According to Elaine Brovont, the director of Midland Meals, Inc., of Lafayette, IN, a MOW site that prepares roughly 1,500 meals daily, operations may use many means of transporting meals, including heated trucks, passenger vans, and individual vehicles (2005). Given this wide range of transport vehicles, some of which are not conducive to maintaining food temperature over an extended period of time, the actual containers used to transport the meals take on added significance. This study focused on maintaining temperature during transportation; more specifically, the effectiveness of different transport containers.

Given the time and temperature constraints during delivery, choosing the correct transport unit is vital. When choosing the proper transport unit, it is important to consider the type of food product as well as the endpoint destination and the intended user. If the transport container fails to function as intended, there is the possibility that much of the time, energy, and expense used in the production of the food product will be wasted, and the health of the recipient could be placed in jeopardy (Robertson, 1993). Insulated nylon bags, insulated hard plastic containers, corrugated paper boxes, plastic bags, and standard thermal coolers are some of the more typical MOW transport containers (Brovont, 2005).

Food transport containers come in various shapes, sizes, and colors, and employ various types of insulation and padding to help maintain food temperature. Also affecting the ability of these containers to maintain food temperature are the types of sealing techniques employed, such as buckles, latches, zippers, and Velcro. Although all MOW operators desire to have the best transport units available, choice is dependent upon cost, ability to maintain temperature, functionality, and durability. Companies test their products before they place them on the market; however, no performance data published by an independent researcher were found for the containers tested in this study.

One way to compare transport units is to determine how fast they lose heat. According to Bertagnoli (1996), even the best packaging will not keep food hot if it has to sit in a car for an hour before it is delivered. Advances in container and insulation design have since improved so that longer holding times are possible for some containers. Theoretically, it is possible to slow the rate of heat loss to the point that the food can maintain its temperature for many hours. In general, the rate of temperature change for food in a container depends upon the rate of heat loss through the container and the heat capacity of the food (Geankoplis, 1983). Once the rate of heat entering one side of the wall of the container equals the rate of heat leaving the other side of the wall, steady-state heat transfer has occurred. Initially, when the food is placed in a container, the temperature of the container's walls will adjust to that of the food. During this time the rate of heat transfer will not achieve steady state. Since the majority of the time that the food is in the container the heat transfer rate will be at steady state, this study's focus was on steady-state heat transfer through the container. The rates of steady-state heat transfer through a container and the heat lost/gained by the food are defined by the equations in Table 1.

Heat or energy leaving the container comes primarily from the food. As the energy leaves the food, the food's temperature falls. The rate that the temperature falls depends not only on the rate that energy is leaving the container, but also on the mass of the food and its heat capacity. Heat capacity (thermal capacity) is the amount of heat required to change the temperature of a substance by one degree (Sears & Salinger, 1975; Wolfram Research, 2006). Table 2 shows the thermal capacity for selected items that may be delivered by MOW. The higher the thermal capacity, the more energy the food can lose before its temperature drops significantly.

Table 1
Steady-State Heat Transfer and Heat Capacity Equations (Geankoplis, 1983)

Steady-State Heat Transfer Equation	Heat Capacity Equations
$q = U A \Delta T$ Where: q is the rate of heat loss U is the overall heat transfer coefficient A is the surface area of the container ΔT is the temperature difference between the inside and the outside of the container	$q = C_p M \Delta T$ Where: q is the measure of the amount of heat lost or gained by the food item C_p is the heat capacity of a food item M is the mass of food item ΔT is the initial food temperature - final food temperature

Table 2
Thermal Capacity (C_p) for Food Items

Food Item	**C_p (kJ/kg*K)**
Water	4.185
Pea Soup	4.10
Milk, skim	3.98 - 4.02
Tomatoes	3.98
Milk, whole	3.85
Cantaloupe	3.94
Apple Sauce	3.73 – 4.02
*Potatoes	3.52
Cream Corn	3.06 – 3.27
Bread, white	2.72 – 2.85
Butter	2.30
Ice	1.95
Ice Cream, frozen	1.88
Flour	1.80 – 1.88
***Note:** Item was used in study to test equipment	

From the steady-state heat transfer equation in Table 1, it is easy to see that the transport container selected has a major impact on how fast the food temperature will drop. The overall heat-transfer coefficient (U) is a function of the amount of insulation, and the surface area (A) is a function of the size and shape of the container. The smaller the overall heat-transfer coefficient, the less heat a container loses. The smaller the surface area, the less heat the container loses. The surface area of the container is minimized compared to the mass of the meals contained when the capacity of the container equals the number of meals contained. Once the U-value and the surface area of the container are determined, one can predict the rate of temperature change given the food's heat capacity and temperature, the mass of food in the container, and the outside temperature. The rate of heat loss by a transport unit divided by the mass and heat capacity of the food defines the rate of temperature drop by the food item (Weast, 1974). It is important to note that the U-value is relatively constant for a container; this means that the food type in the container will not affect U-values. Therefore, the results of this study are applicable regardless of the type of food in the containers.

The final parts of the heat-transfer equations that operators can control are the starting temperature of the food in the container and the temperature of the delivery vehicle. By ensuring that the hot food is as hot as possible and the cold food is as cold as possible when they are placed in their respective containers, the time it takes for food to lose/gain sufficient heat to enter the temperature danger zone can be extended. The difference between the food temperature and that of the air around the transport container is the driving force for heat to move in or out of the food. If the vehicle used to transport the container is too warm in the summer, then the rate of heat transfer into containers with the cold food will increase. Likewise, if the vehicle is too cold in the winter, the rate of heat loss from containers with hot food will increase. As the rate of heat transfer increases, so does the speed at which the food will enter the temperature danger zone.

The purpose of this study was to determine the temperature maintenance capabilities of commonly used transport containers and predict how long they will keep food out of the temperature danger zone. To obtain an appropriate measure of transport equipments' abilities to maintain temperature integrity throughout the delivery process, a U-value or overall heat transfer coefficient was calculated for each container. The overall heat transfer coefficients determined in this study were then used to compare different containers to determine which are better at maintaining meal temperatures.

METHODOLOGY

Thermal characteristics, specifically the ability to maintain temperature, and the rate of heat loss over a period of two hours for 14 containers, were determined by fully loading each of the containers with simulated meals and monitoring the temperature over time with Dynasys'® CyTherm™ Temperature Datalogger Keys. The meals were simulated by using mashed potatoes to represent the 3 oz. of entrée, 6 oz. of vegetables, and 3 oz. of starch. Those amounts are consistent with the revised requirements for MOW meals (Brovont, 2005). For this experiment, mashed potatoes were chosen for several reasons: (1) Mashed potatoes are cost effective, (2) they are easy to prepare, and (3) their thermal properties are relatively consistent between batches. The mashed potatoes were placed in aluminum meal trays sealed with foil-lined lids. The lids were sealed to the trays by crimping the sides of the trays. Meal temperatures were stabilized by placing them in a 120 Volt CresCor® Banquet Cabinet (Holding cabinet) set at 170°F (77°C) for one hour before putting them in the transport containers for testing. Once the meal trays were placed in the containers, the containers were left closed for the duration of the test. Temperatures were measured every minute for two hours using CyberTherm™ Temperature Datalogger Keys.

CyberTherm™ Temperature Datalogger Keys are programmable, key-sized temperature trackers with the capability of displaying visual representations of temperature fluctuations over specified time intervals. In addition to recording the temperature, the Datalogger also records the exact time the temperature was taken. This allowed the data to be synchronized among trays. These thermal characteristics, quantified by Datalogger temperature readings at one-minute intervals, were used to create a linear model describing the ability of these containers to maintain food temperature. The Datalogger keys were initialized using the remote start, then inserted into a small plastic bag to protect the Datalogger key from moisture. The bag with the Datalogger key was then placed in the center of the six-ounce portion of the mashed potatoes, which was in the entrée section of the meal tray. One Datalogger key was placed in each meal tray. When the test was complete, each Datalogger key was downloaded, and the data stored in Microsoft® Excel™ 2003 spreadsheets.

The potatoes were prepared according to the directions on the box. Seven ounces of powered potatoes were mixed with four cups of water. Then the mixture was heated on a gas range until it reached 150°F

(65.6°C). Immediately after the potatoes were removed from the stove, they were portioned into the trays, and Datalogger keys were added. The trays were covered and then placed in the warming unit for one hour to equilibrate the temperatures before they were placed into individual transport units.

The heat capacity of the potatoes was determined by combining 378.41 grams of potatoes at 143.7°F (62.06°C) with 371.25 grams of water at 72.23°F (22.35°C). The change in temperature between the temperature of the water and the potatoes just prior to mixing, and the final mixture temperature, was used to determine the heat lost by the potatoes and gained by the water. Given the mass of the potatoes, their temperature change and the amount of heat they lost, their heat capacity was calculated (refer to Table 1 for formula).

Data were analyzed using Microsoft® Excel™ 2003 spreadsheets to calculate average temperature drop per minute and the rate of heat loss. The rate of temperature loss mutliplied by the heat capacity of the potatoes multiplied by the weight of the potatoes was the calculated rate of heat loss for the container. Using the surface area of the transport containers, the temperature of the laboratory (70°F), the heat loss of the potatoes, and the average temperature of the potatoes in the container, a U-value was calculated for each transport container. The food trays were left in the transport containers for 30 minutes before collecting the data used to calculate the U-value. This was to ensure that steady state heat transfer had been achieved. Steady state was confirmed by graphing the temperature data for each test. Due to resources required to perform each test, each container was tested only one time unless temperature tag anomalies were detected. The final step was to predict the temperature of the food inside the containers when they were one-third full, two-thirds full, and completely full.

Fourteen containers were included in this study. A brief description of each of the containers can be found in Table 3. Three of the containers had built-in electric heaters; the remainder relied only on the insulating properties of the sides, bottoms, and tops to maintain food temperature.

Table 3
Container Descriptions

Container	Description
Cooler	Rigid plastic construction with double-wall urethane insulation, rigid plastic frame with a pressure seal enclosure, and rigid plastic hinge handle
Blue Nylon Two-Compartment Box	Dual compartment nylon box with preformed foam, reflective mylar liner, rigid frame, zipper closure, and straps with plastic clasps for carrying
Purple Plastic Two-Compartment Box	Double-wall polyethylene construction with foam insulation, four side-open doors with recessed stainless steel latches to prevent accidental opening, and gaskets to help ensure an airtight seal
Black Nylon Bag with Lighter Connection	Nylon thermal bag with padded insulation, an electric AC adapter connection plug for use in vehicles, straps with plastic clasps for carrying, and held closed with fabric hook-and-loop fasteners
Box-type Small	Corrugated board box with handles and removable, reflective thermal lining
Box-type Large	Corrugated board box with handles and removable, reflective thermal lining
Red Nylon Bag	Nylon thermal bag with wire support rack, padded insulation, straps with plastic clasps for carrying, and held closed with fabric hook-and-loop fasteners
Gray Plastic Box	Rigid plastic contruction with double-wall blown-foam insulation, recessed stainless-steel latches, and a top that fits into the container to create a seal
Electric Red Nylon Bag	Nylon thermal bag with plastic-covered, padded insulation, cigarette-lighter connection with zipper closure, semi-rigid frame, electric AC adapter connection plug for use in vehicles, and padded insulated insert to place over contents before closing container
Blue Nylon Bag	Nylon thermal bag with foam padding held closed with fabric hook-and-loop fasteners and a padded insulated insert to place over contents before closing container
Electric Plastic Two - Compartment Box	Double-wall polyethylene construction with foam insulation, side- open doors with recessed stainless steel latches to prevent accidental opening, gaskets to help ensure an airtight seal, and electric AC adapter connection plug for use in vehicles
Blue Nylon Bag with	Nylon thermal bag with plastic-covered padded insulation with zipper closure and semi-rigid frame, padded insulated

Zipper	insert provided to place over contents before closing container, and lighter connection for use in vehicles
Cardboard box	Corrugated board box
Plastic bag	T-shirt-style plastic bag (standard grocery bag)

RESULTS

As shown in Table 4, eight of the 14 containers maintained an average food temperature above 135°F (57°C) for the entire two-hour test. Of the remaining six containers, three had final temperatures greater than 130°F (54°C). It is conceivable that those three would have maintained temperatures above the temperature danger zone had the starting food temperature been higher. Table 4 clearly shows the importance of the starting temperature in maintaining temperatures above the temperature danger zone. For example, both the blue, nylon bag with zipper and the blue, nylon two-compartment box had an 18°F (10°C) temperature drop, but the final temperature for the blue, nylon two-compartment box was 8°F (5°C) higher because its starting temperature was higher.

The differences in starting temperatures were due to thermal stratification within the warming cabinet. Because the starting temperature varied, it was hard to accurately compare all containers based on temperature alone. The majority of the non-electrical, commercially available containers appeared to have comparable performance; the range of temperature drop for six of the nine was 5°F (3°C) over a two-hour period. As expected, the three electrical containers were the top performers, and the plastic bag (with basically no insulation) was the worst. The biggest surprise in the study was the performance of the gray, plastic container. Possible reasons for the poor showing by this container will be discussed in the next section.

Because of differences in the containers' starting temperatures, the information in Table 4 can not be used to accurately compare containers. A much better criterion for comparing the temperature-maintenance capability of the containers is their U-value. The results of the calculations for the U-values for each container except the three electic containers are shown in Table 5. The energy used by the electric containers was not measured as part of this study; without knowing how much energy was added to the container during testing, it was not possible to estimate the U-value for the container. For that reason, no U-values were calculated for the electric containers.

The two-compartment containers had the lowest U-values, indicating that they were better insulated and therefore better at maintaining temperature. Though the gray plastic box had the second-highest temperature drop during the test, its U-value was the fifth best among those tested. The U-value is only one of the factors that impacts temperature drop. The others include the surface area of the container, the amount of food contained within, and the food's heat capacity. The gray, hard-plastic container had a relatively high ratio of surface area–to-number of meals contained. This resulted in a larger-than-expected temperature drop based on its U-value. As expected, the corrugated board box and the plastic bag had the highest U-values.

From the U-values it was possible to theoretically predict temperatures in each container if the starting temperature was 150°F (66°C) and the air temperature outside the container was 70°F (21°C). The results of those calculations are shown in Table 6. Those calculations assumed steady-state heat transfer and estimated the energy that would be pulled from the food to warm the container when the food was initially placed in the container.

Table 6 clearly shows the importance of the volume of food and its thermal capacity on the temperature of the food after two hours. Only one of the containers maintained the temperature out of the temperature danger zone. The next three—red, nylon bag; purple, plastic two-compartment box; and blue, nylon bag with zipper--all maintained temperatures of 133°F (56°C) or higher for two hours. The top four performing full containers were the largest four containers. This is because of their thermal mass. That is, they contained the greatest number of meals and consequently the largest amount of energy. Two of those containers—red, nylon bag and blue, nylon bag with zipper—maintained their temperatures better than the two containers with better U-values. The performance of the containers was better than expected as a direct result of the larger amount of meals they contained. The effect of the amount of food on the final temperature was even more evident for the temperatures calculated when the containers were not full. Of the containers that were only two-thirds full, none was able to maintain the temperature above the danger zone for two hours. The temperatures dropped even faster when the containers were only one-third full. The containers with larger surface areas did not fare as well when only partially full because there was more surface area through which energy was lost. This has serious implications when delivering meals to geographically separated individuals.

Table 4
Results of the two-hour holding test in rank order[1] of their ability to maintain temperature.

		Temperature in °F (°C)				
			Temperature drop[2]			
Container	**Meal Capacity**	**Initial**	**30 min [3]**	**1 hr [3]**	**2 hr [3]**	**Final**
Electric Red Nylon Bag	14	161 (72)	3 (2)	0 (0)	-4 (-2)*	165 (74)
Electric Plastic Two-Compartment Box	10	161 (72)	0 (0)	-2 (-1)*	-4 (-2)*	165 (74)
Black Nylon Bag with Lighter Connection	14	149 (65)	1 (1)	3 (2)	5 (3)	144 (62)
Red Nylon Bag	16	154 (68)	5 (3)	9 (5)	17 (9)	137 (58)
Blue Nylon Bag with Zipper	14	157 (69)	6 (3)	10 (6)	18 (10)	139 (59)
Blue Nylon Two-Compartment Box	14	165 (74)	7 (4)	11 (6)	18 (10)	147 (64)
Blue Nylon Bag	10	151 (66)	5 (3)	10 (6)	20 (11)	131 (55)
Cooler	12	157 (69)	8 (4)	13 (7)	22 (12)	135 (57)
Purple Plastic Two-Compartment Box	16	171 (77)	11 (6)	16 (9)	22 (12)	149 (65)
Box-type Large	12	159 (70)	7 (4)	14 (8)	25 (14)	134 (57)
Box-type Small	5	161 (72)	6 (3)	14 (8)	28 (16)	133 (56)
Cardboard Box	12	161 (72)	12 (7)	21 (12)	35 (19)	126 (52)
Gray Plastic Box	6	169 (76)	23 (13)	32 (18)	42 (23)	127 (53)
Plastic Bag	8	159 (70)	14 (8)	26 (14)	44 (24)	115 (46)

*Temperatures with a negative sign increased in temperature during the test.
[1]Based on the total temperature change after two hours.
[2]Temperatures are an average for all meal trays in the container.
[3]Temperature changes over time were calculated by subtracting the new temperature from the initial temperature.

Table 5
Results of the U-value analysis in rank order of the U-value along with surface area and meal capacity

Container	Meal Capacity	Surface area in m²	U-value in w/m² °K	Product of surface area and U-value in w/ °K
Electric Red Nylon Bag	14	0.0129	N/A	N/A
Electric Plastic Two-Compartment Box	10	0.0112	N/A	N/A
Black Nylon Bag with Lighter Connection	14	0.0156	N/A	N/A
Blue Nylon Two-Compartment Box	14	0.0197	0.442	0.00871
Purple Plastic Two-Compartment Box	16	0.0192	0.582	0.01117
Box-type Small	5	0.0107	0.624	0.00768
Blue Nylon Bag	10	0.0127	0.670	0.00851
Gray Plastic Box	6	0.0134	0.711	0.00953
Cooler	12	0.0141	0.731	0.01031
Blue Nylon Bag with Zipper	14	0.0129	0.774	0.00998
Red Nylon Bag	16	0.0140	0.782	0.01095
Box-type Large	12	0.0166	0.801	0.01330
Cardboard Box	12	0.0152	1.236	0.01879
Plastic Bag	8	0.0074	2.590	0.01917

Table 6
Projected temperatures[1] after two hours with containers that were full, two-thirds full, and one-third full of meal trays containing 12 ounces of mashed potatoes.

	Full		Two-thirds full		One-third full	
Container	**Trays**	**Temp.[2]**	**Trays**	**Temp.[2]**	**Trays**	**Temp.[2]**
Blue Nylon Two-Compartment Box	14	137(58)	9	131(55)	5	118(48)
Purple Plastic Two-Compartment Box	16	133(56)	11	126(52)	5	109(43)
Box-type Small	5	123(51)	3	110(43)	2	99(37)
Blue Nylon Bag	10	131(55)	7	124(51)	3	103(38)
Gray Plastic Box	6	119(48)	4	109(43)	2	94(34)
Cooler	12	130(54)	8	122(50)	4	104(40)
Blue Nylon Bag with Zipper	14	133(56)	9	126(52)	5	112(44)
Red Nylon Bag	16	134(57)	11	128(53)	5	110(43)
Box-type Large	12	127(53)	8	118(48)	4	99(37)
Cardboard Box	12	119(48)	8	109(43)	4	90(32)
Plastic Bag	8	111(44)	5	97(36)	3	83(28)

Note: Containers are arranged in order of increasing U-value as shown in Table 5.
[1]Based on the experimental U-value, a starting temperature of 150°F (66°C), and an outside temperature of 70°F (21°C).
[2]Temperature in °F (°C).

DISCUSSION AND CONCLUSIONS

Clearly the type of transport container used is very important for maintaining temperature and food integrity during transport. Unfortunately, the high cost associated with some of the better-performing containers makes them too expensive for many "budget-strapped" MOW providers. The best-performing containers, those with electric heating units, were two- to three-times the cost of the non-electric unit. If an operation can afford the transport containers with electric heating units, it is recommended that they do so because these containers can maintain safe temperatures much longer than other containers (see Table 4). Of the remaining containers, only one was projected to maintain temperatures above 135°F (57°C) for two hours given the conditions in Table 6. None of the containers was projected to keep the food outside the temperature danger zone if only one-third or two-thirds full. This has serious implications because the temperature-maintenance capabilities of the containers are significantly decreased as meals are delivered.

To ensure that food temperature is properly maintained during delivery, MOW can take a number of actions even if they cannot afford the electric units. First, they need to select durable containers with adequate insulation; cardboard boxes and plastic bags do not provide adequate barriers to heat loss and do not safely maintain food temperatures. Another selection criterion should be the size of the container. It is important that the size of the container be matched to the number of meals on the delivery route. For example, while both the blue, nylon, two-compartment box and the purple, plastic, two-compartment box maintained higher food temperatures than the box-type, small container when they were full, both performed worse than the box-type, small container when they held only five meals – the same number as the full, box-type, small container. As meals are delivered, the temperature maintenance capacity of all containers decreases; however, if an appropriately sized container is used, the temperatures can be maintained for a longer time.

Another important selection criterion is the resistance to heat flow through the container. The measure of the resistance to heat flow is the U-value; the lower the U-value, the better. While the U-value is important, by itself it does not provide a complete picture of the container's ability to hold heat and temperature. The total surface area of the container also impacts the rate of heat loss. For example, the U-value for the blue, nylon bag with a zipper was 1.75 times that of the blue, nylon, two-compartment box. Since both hold 14 meals, the projected temperature loss by the blue, nylon bag with a zipper should have been almost twice that of the other container. According to Table 6, the temperature drop was only 4°F (2°C) different for the two containers. The reason for the similar performance of the two containers, despite the great disparity in U-values, was the total surface area of the containers. The surface area of the blue, nylon bag with a zipper was only 65.5% of the surface area for the blue, nylon, two-compartment bag. A better measure of how a container is expected to perform would be the product of U-value and surface area. The resulting product for the two containers was 0.00871 w/°K and 0.00998 w/°K for the nylon, two-compartment box and the blue, nylon bag with zipper, respectively. This difference is more in line with the predicted temperature loss in Table 6. Therefore, it is possible to purchase a container with a much better U-value than its competitors, but not gain any significant increase in holding time. When selecting a container, operators must also consider the size of the container. It is important that the container have the smallest surface area possible and still hold the required number of meals.

After selecting the best container, a MOW operation can take a number of actions to help ensure that the food stays out of the temperature danger zone during delivery. First, it needs to maintain as short a route as possible. By shortening the routes, there is less time for the food to lose heat and drop in temperature. While this is a logical way to protect food integrity, it is likely not a practical solution for most operations. A better solution is to ensure that the food be as hot as possible when placed into the containers. In the temperature ranges seen during delivery, the rate of heat loss and temperature drop will be relatively constant. Ensuring a higher starting temperature means that it will take longer for the temperature to enter the danger zone. One point of concern when electing to start with a higher starting temperature is the effect it will have on the food. Higher temperatures can seriously degrade the quality of a number of different food items. This is not a problem for many of the foods served by MOW programs. To ensure food safety, many of the foods served are cooked to temperatures of well over 165°F (74°C) -- temperatures well above the 150°F (66°C) used in the theoretical evaluation of the containers.

In addition to starting with a higher temperature, MOW can help maintain meal temperature in additional ways. First, the containers can be preheated before the food is added. Preheating the containers will reduce the initial heat lost by the food as the container temperature rises to that of the food. The amount of heat required to bring the container up to temperature varies, depending upon the container. The resulting temperature drop is further impacted by the number of meals in the container. For the containers evaluated in this study, the temperature drop due to not preheating the containers ranged from 8°F (4°C) for a full gray plastic box, to basically 0 for the plastic bag. The effect for partially loaded containers was even greater: The meals in the gray plastic container experienced a 20°F (11°C) temperature drop when only two meals were placed in the container. In general, the rigid containers required more energy, resulting in greater meal temperature drops to warm the container than did the bag-type containers. Preheating can be done by placing plastic containers of hot water in the containers prior to adding the food.

Operators also have the option of adding "heat sinks" to containers in order to help maintain temperature. A heat sink is an object with a high heat capacity. Examples of heat sinks include non-toxic gel packs and metal or ceramic plates. Without a heat sink, the heat that leaves the container comes from the food. If material with a high heat capacity is added to serve as a heat sink, then a significant portion of the heat leaving the container will come from the heat sink and not the food. With less of the heat that leavesthe container coming from the food, the temperature drop of the food will be slowed, and it will stay out of the danger zone longer.

Considerable attention must also be given to some of the containers' practical features, which include safety, capital costs, and ease of use. Given that many of the delivery drivers are older volunteers, precaution must be taken to ensure that these individuals are not injured when opening, closing, and transporting the containers. The containers with recessed stainless-steel latches could seriously injure the typical volunteer delivery driver because of the pressure necessary to open and close and the effort necessary to fasten the pieces of a given container. These individuals also run the risk of getting their fingers caught in the buckle or latch. The recessed stainless-steel latches are associated with the hard, plastic, box-type containers, which are bulkier and weigh considerably more than the other types of containers. This presents a huge obstacle to maintaining the temperature integrity of the meals until the point of delivery at the participant's doorstep. These containers come with a hefty price tag, and the cost of the electric attachment to a hard plastic box makes it unaffordable for most MOW operations.

The containers with the zipper enclosure do not pose a significant safety threat; however, they can prove to be very impractical. These containers come with an easy-to- manage strap for carrying and are relatively affordable, given their durability. The cardboard boxes and plastic bag options do not have any noteworthy safety risks. These containers also have handles that over time may succumb to wear and tear. They are very affordable for MOW operations; however, they are largely ineffective. To keep food safe during delivery, personnel must not allow food temperature to enter the temperature danger zone. To ensure that this does not happen, MOW programs should take a hard look at how they are transporting meals. Just putting the meals in an insulated transport container may not be enough to properly maintain appropriate temperatures.

This study has provided information that can be used by MOW programs in selecting transport containers based on their ability to maintain temperature when they are closed. Several operational considerations that affect container selection were not addressed by this study. The first of these is heat loss when containers are opened to remove meals. Different closure designs are very likely to impact the amount of heat lost during opening. Next, would be the overall durability of the container. This is an extremely important characteristic, particularly if an operation uses volunteer drivers, and the vehicle is not designed to transport food. Finally, although preheating the containers and using heat sinks to help maintain temperature are theoretically sound recommendations, the exact impact of each should be tested under both laboratory and field conditions.

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