SEMI E32-0697
MATERIAL MOVEMENT MANAGEMENT (MMM)

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1 Introduction

Automated material movement represents a significant milestone in the evolution of automation in semiconductor manufacturing. The standardization of the transfer process is critical to the economic viability of material movement automation. This Standard addresses the communications needs of the semiconductor manufacturing facility with respect to material movement.

1.1 *Purpose* — This Standard addresses automated material movement on the semiconductor factory floor—the task of transporting objects (material, *et al.*) from one processing or storage location to another. It defines the concepts of material movement, the behavior of the equipment (including transfer devices) in relation to material movement, and the messaging services which are needed to accomplish the task.

1.2 *Scope* — The scope of this Standard is defined from two viewpoints. The first is the breadth of the functionality covered. The second is the depth to which it is covered.

The breadth of functionality covered by this Standard is limited to the activity required to transfer an object from a location on entity 'A' to a location on entity 'B' under the supervision of a factory host. This transfer may occur directly between two factory process equipment, or may involve the assistance of a 'transfer agent', a device dedicated to material transfer. Thus, the material movement domain includes a maximum of four types of entities (see Figure 1):

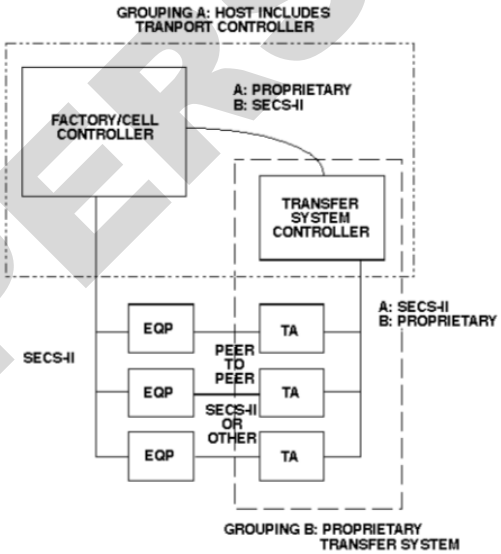

Figure 1
Illustration of Material Movement Scope

1. The factory host, which might, for example, be a factory controller or cell controller.
2. The set of process-related equipment, to which the host communicates.
3. The transfer agent, which performs the physical transport of the material in the factory. The transfer agent might communicate directly with the host or be controlled by an intermediate system.
4. This intermediate system, the transfer system controller, is the fourth type of entity.

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This Document assumes that the transfer system controller is either a part of the host or a part of a potentially complex transfer agent (as shown by the dotted boxes in Figure 1). Thus, the term 'transfer system controller' seldom appears. The case where a 'transfer agent' is actually a transfer system controller plus multiple transport devices is discussed further in § 4.1.6.

There are some forms of material movement that do not fall within the domain of this Standard and thus are not applicable to the methods described below. One example might be a non-deterministic system, such as a conveyer where generic parts are placed onto the system and circle until randomly selected by a workstation needing that type of part.

The subject of alarm reporting is not covered in this Document. While material movement-related alarm situations will exist, the definition of the mechanism for reporting such alarms is left to other Standards Documents.

This Standard presents a solution from the concepts and behavior down to the messaging services. It does not define the messaging protocol.

A messaging service includes the identification that a message shall be exchanged and definition of the data contained within that message. It does not include information on the structure of the message, how the data is represented within the message, or how the message is exchanged. This additional information is contained with the message protocol.

The defined services may be applied to multiple protocols. Information on the mapping of material movement services to specific protocols (e.g., SECS-II) are added as adjunct Standards.

1.3 *References* — The following SEMI Standards are related to the Material Movement Standard:

SEMI E5 — Specification for SEMI Equipment Communications Standard 2 Message Content (SECS-II)

SEMI E23 — Specification for Cassette Transfer Parallel I/O Interface

SEMI E30 — Specification for Generic Model for Communications and Control of SEMI Equipment (GEM)

SEMI E39 — Object Services Standard: Concepts, Behavior, and Services

Other References:

ISO/TR 8509:1987, Information Processing Systems, Open Systems Interconnection — Service Conventions

Harel, D., "Statecharts: A Visual Formalism for Complex Systems." Science of Computer Programming 8 (1987): pp. 231–274[1]

1.4 *Conventions*

1.4.1 *State Models*

Definition of behavior of systems or subsystems is based upon state models using the Harel notation. A discussion of this notation is available in the article by David Harel referenced above.

The Harel notation does not include the concept of 'creation' and 'deletion' of state models to represent transient entities. The 'transfer job' described in this Document is such an entity, where each new transfer job created uses a copy of the same state model. In this Document, the use of an oval is used to denote the creation of an entity and also the deletion of that entity.

Transition tables are provided in conjunction with the state diagrams to describe explicitly the nature of each state transition. A transition contains columns for Transition #, Current State, Trigger, New State, Action(s), and Comment. The 'trigger' (column 3) for the transition occurs while in the 'current' state. The 'actions' (column 5) include a combination of (1) actions taken upon exit of the current state, (2) actions taken upon entry of the new state, and (3) actions taken which are most closely associated with the transition. No differentiation is made.

1.4.2 *Object Services* — SEMI E39 Object Services Standard (OSS) requires that standardized objects be subtypes of the Top Object, that their attributes be defined in a table format and include specification of the value for object type, and that the objects support the GetAttr and SetAttr services. See SEMI E39 for details.

Standardized objects are supported by an attribute definition table with the following column headings:

[1] A brief tutorial on the Harel Statechart Notation is provided as Related Information 1, § R1-5 of the SEMI E30 (GEM) Standard.

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Attribute Name	*Definition*	*Access*	*Reqd*	*Form*
The formal text name of the attribute.	Description of the information contained.	RO or RW	Y or N	Any valid form. (See below.)

Access — RO (Read Only) or RW (Read and Write) to indicate the access that users of the service have to the attribute.

Reqd — A 'Y' or 'N' in the Required (Reqt) column indicates if this attribute must be supported in order to meet fundamental compliance for the service.

Form — Indicates the format of the attribute. (See § 4.5.2 for definitions.)

2 Definitions

The following definitions are arranged in alphabetical order. Some are defined using terms defined elsewhere within this section. Please reference such definitions as needed. No references beyond this section should be necessary for a basic understanding of these terms.

Active Transfer Partner — (Opposite of Passive Transfer Partner) A transfer partner is considered active when it physically participates in the micro level portion of the transfer, either by moving the transfer object or by moving impediments within the transfer envelope (e.g., doors, clamps). This term refers to the micro level transfer phase only, and not to any setup activities prior to the transfer (e.g., a port door may be opened during setup phase by passive partner).

Atomic Transfer — The basic unit of movement. The transfer of a single transfer object from Equipment A directly to Equipment B where only one change in ownership occurs.

Compound Transfer — Combination of two or more atomic transfers executed sequentially or concurrently to achieve a single goal (e.g., exchange carriers or move a carrier between process machines using a transfer agent).

Dynamic Port — (Opposite of Static Port) A port with associated mechanisms capable of assisting with the physical movement of a transfer object or of interfering with the transfer of an object during the transfer. Such mechanisms may include doors, elevators, and robot arms. A transfer partner using a dynamic port for the transfer may be active or passive as required.

NOTE 1: The concepts of 'dynamic' and 'static' are associated with a port rather than equipment, as equipment may have both dynamic and static ports.

Equipment — Mechanical entity in the factory which plays a role in the manufacturing process. The equipment referenced in this Document include machines used for processing, transport, and/or storage of material (see definition of material).

Host — In the context of material movement, the host is an entity, generally separate from either transfer partner, which coordinates and supervises a transfer job.

Interactive Transfer — A transfer in which both partners are active and must interact in the performance of the transfer.

Interfering — A dynamic port is interfering when any of its associated mechanisms are positioned where they are capable of physically obstructing the transfer.

Macro Level — Level of material movement that involves coordination by the host but may not require knowledge of the physical process used to accomplish the material transfer.

Material — A term used interchangeably with 'transfer object' to refer to discrete objects which may be transferred to and from equipment. This may include product, carriers, reusable fixtures, etc. See transfer object definition.

Material Location — A physical position on a piece of equipment at which a transfer object may reside. Many material locations may be accessed directly through a port, but this is not a requirement. Some material locations internal to the equipment may not be accessible by a transfer agent.

Message Service/Service — A service (or a message service) represents a set of functions offered to a user by a provider. An unconfirmed service consists of a sequence of service primitives—the request from the sender to the

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communications facility and an indication to the receiver from the communications facility. Each of these service primitives is described by a list of parameters. A confirmed service adds a response to the initial request. The primitives for a response are called the response and the confirmation. A service excludes definition of message structure and protocol.

Micro Level — Level of material movement characterized by peer-to-peer interaction of the transfer partners to achieve synchronization of the detailed mechanical steps of material transfer.

Object — Webster's defines an object as 'something perceptible.' In the software world, an object is a combination of attributes and behavior. It may refer to something concrete, such as a transfer object, or to a concept, such as a transfer job.

Ownership — An equipment is said to 'own' a transfer object from the time the object is transferred into one of its ports until it is transferred out of the equipment. This indicates that the equipment has physical control of the transfer object.

Passive Transfer — A transfer that involves one active and one passive partner. During a passive transfer, the active partner retains control of the transfer envelope during the entire physical transfer.

Passive Transfer Partner — (Opposite of Active Transfer Partner) A transfer partner is considered passive when it takes no part in the physical micro level transfer, moving nothing within the transfer envelope. This term refers to the physical micro level transfer phase only. Setup activities prior to the transfer may be performed by a Passive Transfer Partner (e.g., a port door may be opened during setup phase).

Port — A point on the equipment at which a change of equipment ownership of a transfer object occurs. A port is not itself a material location, but shall have an associated location. A port may be thought of as an access point to a material location on an equipment. The definition of the term port includes any dedicated mechanisms that either prepare for, facilitate, or are capable of interfering with the transfer. All equipment shall have a minimum of one port.

NOTE 2: While they are of use to the host system, the commonly used designations 'Input Port' and 'Output Port' are irrelevant in the context of this Document. They are based on a flow of material through an equipment rather than the movement of transfer objects (which may be carriers rather than the material itself). Transfer objects may have to be moved into and out of both these types of ports.

Receiving Port — For a specific transfer, the port into which a transfer object is to be placed.

Sending Port — For a specific transfer, the port from which a transfer object is to be removed.

Static Port — (Opposite of Dynamic Port) A port with no associated mechanisms capable of assisting or interfering with the transfer of an object. A transfer partner utilizing a static port for the transfer shall always be passive.

Transfer Agent — An equipment specialized to the transport of material from one equipment (or storage area) to another.

Transfer Envelope — The three-dimensional space occupied during the transfer by the transfer object and all associated transfer mechanisms of both transfer partners. This defines the space in which transfer activity occurs and in which the potential for physical interference with the transfer exists.

Transfer Job — The set of atomic transfers constructed by the host to accomplish a cohesive material movement objective. See the section on compound transfers below.

Transfer Object — A physical object that is transferred to and from equipment, such as a product material, an empty carrier, or a carrier containing material to be processed. Tools (e.g., stepper reticles) and expendable materials also may be transfer objects. The term 'material' is used interchangeably with 'transfer object.'

Transfer Partners — In a given atomic transfer, the equipment sending a transfer object and the equipment receiving the transfer object are transfer partners.

Transfer Specification — The list of data provided by the host to define an atomic transfer.

Transfer System Controller — Entity that is responsible for management of multiple transfer agents. The transfer system controller presents a single communications interface to its host representing these multiple agents.

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3 Overview

Material movement is concerned with the transfer of objects (WIP, tools, expendable materials, etc.) among process equipment, buffers, and storage facilities. These objects may optionally be contained (singly or in mass) within a carrier. Empty carriers may also be considered objects.

Material movement may include several different types of entities. These are divided into two classes: Host and Equipment. The host is the supervising entity which organizes the transfer and gives the appropriated instructions to each equipment involved. An equipment physically participates in the transfer, either sending or receiving material. The class of equipment may be divided into three types:

Process Equipment — Equipment which performs value-added operations on the factories' products. This includes those equipment which physically changes the product and those which measure/test the product.

Transfer Agent — A type of equipment specialized to the movement of transfer objects from place to place within a factory. Transfer agents themselves may be of different types and with widely-differing characteristics. These may be fixed-arm robots, robot arms on a fixed track, AGVs with or without robot arms, overhead gantries, cars on tracks, or even transfer systems containing a heterogenous collection of other transfer agents. Humans also may act as transfer agents.

Storage Areas — A type of equipment used to hold transfer objects pending further processing (if product) or use (if reticles, etc.) within the factory. A storage area may be as sophisticated as an automated WIP Bin or as simple as a shelf.

3.1 *Macro and Micro Levels* — Material movement is separated into two levels. The more abstract level, called the macro level, consists of all message transactions used by the host in its coordination role. At the macro level, the host is responsible for determining what material is to be moved, from where, to where, and when. The host shall provide each party involved in a transfer job with the information necessary to perform its part of that transfer job.

A transfer job may be composed of multiple handoff operations, or 'Atomic Transfers.' Each atomic transfer involves only two equipment, termed 'Transfer Partners.' In order to perform this handoff operation, the transfer partners must achieve a level of synchronization. The communications between the transfer partners is called the micro level of material movement.

These communications occur between the two partners in a 'peer-to-peer' fashion. Micro communications may be implemented via a direct equipment-to-equipment connection[2] or by passing messages indirectly through the host.

The macro and micro levels are designed to work together so that the host may initiate the transfer and then allow the transfer partners to perform the job interactively. However, these two levels may be used separately. For instance, the macro level may be combined with functionality of the SEMI E23 (Cassette Transfer Parallel I/O Interface Specification) Standard. Additionally, under some conditions there may not be a host coordinating the transfer. Instead, one of the transfer partners might be in control. Here, the micro level may still be used to accomplish the transfer. The controlling partner would perform the coordination functions normally in the domain of the host.

In this Standard, the macro and micro levels are defined separately, each with its concepts, behavior, and services.

3.2 *Ports and Locations* — A port may be considered a point of entry to the equipment. A location is a receptacle for a transfer object. At any time, a port shall be linked to at least one location. However, some locations may be internal and never be linked to a port.

For 'typical' factory equipment, there is a permanent one-to-one correspondence between the port and a location. However, not all semiconductor equipment follows this pattern. For instance, the port on a transfer agent that includes a robot arm and multiple on-board storage locations is actually the gripper on the robot arm. The gripper is also a location. In another case, a port may actually feed a rotating carousel containing multiple locations. The port in this example would be the access door to the carousel. The location linked to this type of port would be the one in front of the door at transfer time and would change whenever the carousel rotates. Figure 2 helps to illustrate the difference between ports and locations.

[2] In this context, connection is intended to mean a direct logical link, rather than a hard wired connection.

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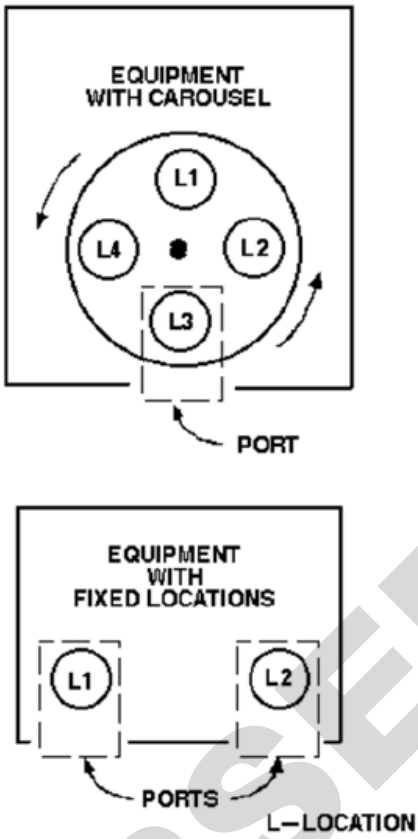

Figure 2
Port vs. Location

It is important to note that the attribute of 'full' or 'empty' belongs to a location rather than a port. A port that has just *received* a transfer object may be able to receive another immediately. Likewise, a port that has *sent* a transfer object may have more material available to send.

3.3 *Compliance* — Compliance to this Standard includes adherence to all stated requirements in this Document. This includes all defined messages services, state models, and communications scenarios.

This Standard may be divided into two parts:

- Material Movement Macro Level, and
- Material Movement Micro Level.

An equipment may be compliant to one of these parts without the other. Details of compliance to each of these parts are defined in the body of this Document.

4 Macro Level

The set of host<->equipment interactions needed to facilitate a transfer is called the macro level. These interactions concentrate on the definition of the transfer specification, and leave the details of the physical transfer to the micro level interactions.

In addition to the services defined in § 4, the GetAttr service defined by SEMI E39, Object Services Standard, is supported by this Standard. The definition for the GetAttribute service defined in § 4 will be removed and no longer supported in 1998.

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4.1 *Macro Level Concepts* — The macro level is designed with the intent of creating a widely applicable, host coordinated material movement capability. The result is a sequence of interactions from host to equipment that is used to accomplish the coordination of material movement required on the manufacturing floor.

The elements of material movement common to all transfers make up the framework. Other elements which differ from implementation-to-implementation are pushed, as much as possible, into the data portions of communications. The common elements identified are as follows:

- The host is responsible for designating the transfer partners which are compatible for transfer.
- The host must supply the necessary information for the transfer to each partner.
- Once transfer is defined, the responsibility moves to the transfer partners, especially the designated 'primary' partner.[3] The host may monitor the transfer, but leaves the details to the transfer partners.
- The transfer partners inform the host of milestones during the process and of process completion.

Some of the elements which are more implementation-specific are:

- Which partner is the sender and which is the receiver of material. This has no intrinsic relationship to other details, such as the selection of the primary transfer partner.
- Whether a transfer partner is passive or actively participates in the transfer. This also becomes a data issue.
- The method (mechanism) of an interactive transfer. This may vary depending on the transfer partners' capabilities and system design. Interaction with different partners may require different methods. Transfer recipes containing this information may be specified by the host as a part of the transfer specification.

The host must have some knowledge of the capabilities of the transfer partners it designates to perform a transfer. It must understand which partners are compatible. If compatible, it must know the proper role for each partner of the transfer and what methods must be used. If an interactive transfer is warranted, the host must be able to determine which partner should be the primary. Definition of the mechanism for such determinations by the host is beyond the scope of this Document.

4.1.1 *Macro Level Definitions*

4.1.1.1 *Abort* — The immediate termination of an active job, including a complete stop of all transfer job-related movement. An abort may be initiated by the host (and optionally by the operator). An abort by the host is directed at a transfer job, not at an individual atomic transfer. When told to abort, a transfer job shall, in turn, abort its atomic transfers. The abort command is intended to be used only in situations where there is risk of material or hardware damage.

4.1.1.2 *Allocate* — The formal reservation of an entity's resources for a specific purpose. In this Document, it refers to the reservation of an equipment's resources for a specific transfer job or atomic transfer. Allocation of needed material locations for a transfer job occurs just prior to that job becoming active. Allocation of required port-related resources occurs just prior to the start of an atomic transfer.

4.1.1.3 *Commit* — The commit by the equipment indicates a readiness to begin the actual material handoff. The commit follows any setup activities and coincides with entry to the HANDOFF state. For example, an AGV may not be allowed to commit until it has moved to the point of transfer. The point at which an equipment may commit is equipment-specific. There is a separate commit for each atomic transfer in a job.

4.1.1.4 *Deallocate* — The release of allocated resources. In this Document, it refers to the equipment's release of the resources reserved for a transfer job or an atomic transfer.

4.1.1.5 *Port Resources* — Equipment-controlled mechanisms that serve a port. An example of a port resource is a cassette indexer that changes to elevation of the material location. A port resource is available only to the atomic transfer that has allocated that port.

4.1.1.6 *Primary Transfer Partner* — The partner that controls the micro level transfer and that would receive the optional host command to initiate the transfer. The primary transfer partner shall always be an active partner for the

[3] See the definition for 'primary transfer partner' in ¶ 4.1.1.6.

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transfer. For an interactive transfer, the nature of the transfer partners may determine which should be primary. Otherwise, the host may choose.

4.1.1.7 *Restore* — An operation associated with a transfer job which causes the resources used by that job to be returned to the preferred idle conditions (e.g., port access door closed). When a transfer job involves multiple ports on an equipment, restore activities are done on a port-by-port basis as each port is no longer needed by the transfer job.

4.1.1.8 *Secondary Transfer Partner* — The opposite of the primary transfer partner. This partner is either passive during the transfer or is controlled by the primary transfer partner. If active, this partner shall await communications from the primary partner before acting (see micro level).

4.1.1.9 *Setup* — A process associated with an atomic transfer that causes the port resources to achieve required pre-transfer conditions (e.g., port access door open).

4.1.1.10 *Stop* — A command available to the host that causes an orderly termination of a transfer job. Upon receipt of a stop command, the equipment shall complete all currently active atomic transfers, execute the 'restore' process, and then terminate.

4.1.2 *Atomic Transfer* — An atomic transfer is the handoff of a transfer object from one equipment to another. This is the fundamental building block of material movement. An atomic transfer includes the minimum number of physical participants in the move: one sender and one receiver. Thus, only one change of ownership shall occur in an atomic transfer. All transfers required in practice can be constructed as a series of atomic transfers. A set of atomic transfers combined to make a complex but cohesive transfer is called a compound transfer.

4.1.3 *Compound Transfer* — On the factory floor, many material transfer situations will require multiple atomic transfers. For example, the host may determine that a material carrier needs to be moved from equipment 'X' to equipment 'Y' by transfer agent 'T.' To accomplish the transfer would require two atomic transfers, first 'T' acquires the carrier from 'X,' then it delivers it to 'Y.' A compound transfer might involve several equipment and include parallel as well as sequential execution of atomic transfers.

4.1.4 *Parallel Transfers* — Each port on an equipment is a separate entity. It is possible, within the limitations of the equipment and transfer agents, to execute parallel transfers involving separate ports on an equipment. These parallel transfers may be with the same transfer partner, or with multiple partners. There are no inherent restrictions to a transfer job simultaneously executing multiple atomic transfers on an equipment. If an equipment's ports are static (i.e., always passive), the equipment should allow parallel transfers. If the ports are dynamic, there may be some sharing of resources which could limit this (e.g., use of the same robot arm). An equipment is not required to allow parallel transfers.

4.1.5 *Transfer Recipe* — The transfer recipe is an element of the transfer specification. The scope of a transfer recipe is one atomic transfer. A transfer recipe may contain information defining the following aspects of a transfer:

- setup/restore operations,
- sequence of handoff operations (see micro level),
- micro level commands to be issued by the primary partner to the secondary transfer partner,
- parameters relating to the transfer.

Thus, the host may use the transfer recipe to communicate the details that make it possible to prepare for and carry out the micro level transfer.

Use of transfer recipes is not a requirement. However, these recipes provide for dynamically 'programming' an equipment to interact properly with what may be a completely different type of equipment. For instance, it may be possible to 'teach' one transfer partner the proprietary commands that the other partner understands by embedding those commands in a transfer recipe. During the transfer, the primary partner could issue those commands at the proper time using standard micro level messages (see § 5).

Transfer recipes should be created and managed according to applicable SEMI Standards and in a similar manner to other types of recipes on the equipment (e.g., process recipes).

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4.1.6 *Transfer System Controller as Transfer Agent* — A transfer agent is an entity to which transfer-related commands are given in order to carry out transfer jobs. A transfer system, which might include several material transport devices, can be described the same way. However, there are some important differences.

There are a number of ways that a host could view a transport system, including:

- as a single transfer agent with numerous ports,
- as a single transfer agent with a single port and numerous internal locations,
- as multiple logical transfer agents with their own ports, or
- as the set of real transfer agents that the transfer system controls.

The transfer system may conceal from the host the various internal operations (e.g., handoffs, travel paths) that it uses to complete a transfer. It may even hide the actual physical location (or series of locations) and provide a logical location for host reference.

4.1.7 *Transfer Job* — The host's material transfer objectives are defined in a transfer job. This transfer job may be a single atomic transfer or a compound transfer. A compound transfer job consists of multiple atomic transfers grouped together to accomplish a more complex objective. A typical compound transfer may also be accomplished by creating a separate transfer job for each required atomic transfer. The decision to group atomic transfers into a transfer job is application-dependent.

The key advantages to the use of compound transfer jobs are the reduction of the communication overhead to the host and the streamlining of the transfer process. The communication overhead is reduced by the fact that the host can define a number of atomic transfer operations with a single message to the equipment. The equipment are not required to wait for host commands between these atomic transfers.

The process is streamlined by virtue of the removal of redundant physical activities during the transfer job. Total setup and restore time for a port may be reduced if the setup for consecutive atomic transfers is similar.

One example of streamlining would be the 'exchange' of carriers between equipment, where a transfer agent might bring an empty carrier to replace a full carrier on the 'output port' of a machine. If the port has a door that is opened during transfer preparation and closed during the restore phase, the door would be better left open for both atomic transfers. Upon completion of the removal of the first transfer object, rather than close the door, the new transfer is begun and the door left open. The two atomic transfers would thus be executed as one smooth 'swap' transfer without wasted time.

Equipment View of Transfer Job — A transfer job may involve a number of equipment and ports. Each of the involved equipment is given a Transfer Job Create request that specifies only the portion of the overall transfer job that involves that equipment. Only the host is guaranteed a complete picture of a compound transfer. In the example where a transfer job was created to move a transfer object from 'X' to 'Y' via transfer agent 'T,'

- 'X' would see send material to 'T,'
- 'Y' would see receive material from 'T,' and
- 'T' would see get material from 'X' and put material on 'Y.'

Atomic Transfer Sequencing Guidelines — When the transfer job given to an equipment contains multiple atomic transfers, the guidelines for performing those transfers are:

- Atomic transfers for a specified port are performed in the sequence given.
- When a transfer job references multiple ports on the equipment, these ports may execute their atomic job sequences in parallel to the other ports.

See Figure 3 for an illustration of the flow of a complex transfer job from the view of one equipment. The three parallel paths show a possible chronology for a transfer job.

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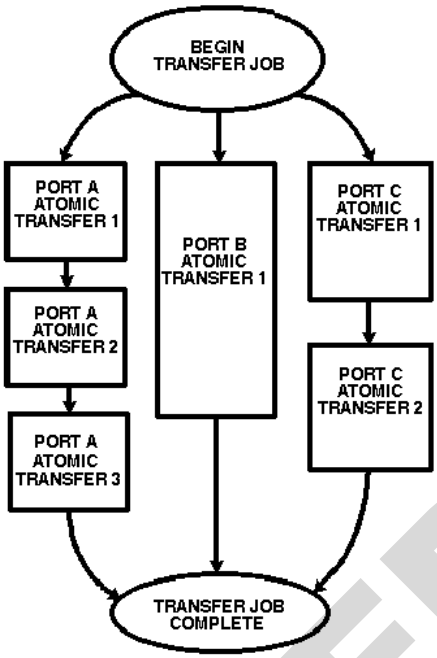

Figure 3
Transfer Job Sequencing

There are exceptions to the sequencing guidelines above. One case would be a device designed to simultaneously transfer from multiple ports on one machine to corresponding ports on another. This would translate into synchronized parallel atomic transfers on separate ports. Another case would be two atomic transfers involving the same port that might happen concurrently. That is, a transfer object is transferred out of the port at the same time[4] another is transferred in. In either of these cases, the equipment is responsible for:

1. recognizing that such transfers can and should be combined and
2. synchronizing the execution of the transfers.

Multiple Transfer Jobs — Multiple transfer jobs may exist simultaneously on an equipment. Although not a requirement, an equipment may

1. queue transfer jobs for later execution or
2. allow them to execute in parallel with other transfer jobs.

Queued transfer jobs and parallel transfer jobs are separate concepts, either of which may be supported.

Resource Allocation/Deallocation — Transfer jobs allocate the needed material locations prior to beginning. These material locations remain allocated until the transfer job chooses to release them. In many cases, a material location is physically linked with a single port, and the allocation of that location infers allocation of the port. However, this is not a requirement.

If the material locations for a transfer job are not available or are not in the proper state, the job shall be rejected or queued (if queuing supported and queue not full). For the transfer job to begin, each location referenced in the equipment's transfer job must contain the proper material for the first atomic transfer which would use that location.

If parallel transfer jobs are supported and the necessary locations are available, a second (or third, etc.) transfer job may begin execution.

[4] 'At The Same Time' in this case means that both atomic transfers are in progress. It does not imply that both transfer objects must move simultaneously.

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In some cases a port may provide direct access to multiple locations. This may be true for the specialized ports described in § 3.2 and in cases where the port serves as a pass-through to internal locations. For each atomic transfer, the needed port and its resources are allocated just prior to the start and released (deallocated) at the end of that atomic transfer.

4.2 *Macro Level Behavior*

4.2.1 *Macro Level Communications* — This section provides a high-level definition of the communications between the host and each transfer partner needed to achieve the macro level of material transport. This is not intended to define the messages, but rather to describe the concepts. The message detail is addressed in the Macro Level Services § 4.4. § 4.2.2 shows how these messages are integrated into the transfer job behavior model.

First, the control message flow is presented as Figure 4. Then additional informational messaging is described (see Figure 5). The arrows represent significant information exchange. Some replies that do not contain significant information may not be shown.

The ordering of the messages between one partner and host shall be retained. The key synchronization point between the partners at the macro level is that both partners shall complete their setup activities before the 'atomic transfer started' event may occur.

4.2.1.1 *Macro Level Job Control* — Figure 4 illustrates the job control-related message flow expected on a normal transfer as seen by the host. These messages are used to control the material movement process. This diagram assumes a simple transfer job involving only two partners and only one port on each. It also assumes that the partners take the same role (primary or secondary) for each atomic transfer that occurs. The messaging is no different if these assumptions are not made, but diagrams become quite difficult to create.

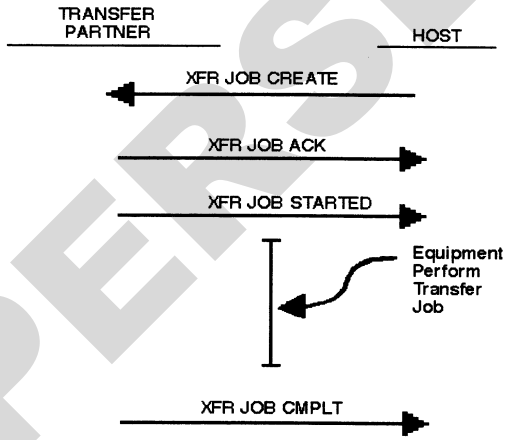

Figure 4
Macro Level Message Flow

Transfer Job Create — The host requests that the device participate in a specified transfer job. This may consist of a single atomic transfer or a compound job. This request may be acted upon immediately or, if necessary resources are currently busy, saved for later execution.[5] The request shall supply a transfer specification for each atomic transfer, in which the host supplies such information as:

- which port is to be used,
- whether the port is to send or receive material,
- identification of the material to be transferred,
- role of the equipment (primary or secondary transfer partner),

[5] If the equipment does not support queuing or if the queue is full, the request may be rejected.

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- mechanism or recipe to be used in the transfer,
- identification of the other transfer partner, and
- an identifier for the atomic transfer.

Upon receipt of the Transfer Job Create request and before acknowledging, the equipment should check the transfer specification(s) to ensure that they are valid. That is, that the specified parameters (ports, transfer recipes, role of the equipment, etc.) have legal values. Depending upon its ability to queue jobs, it may check such dynamic information as presence of transfer object, availability of resources, etc. to determine whether to accept or reject.

Transfer Job Create Acknowledge — The equipment responds to the host that the requested job is accepted or rejected, and if rejected, supplies the reason.

Transfer Job Complete — Once a transfer partner completes the restore operation, it declares the transfer job to be complete. This message is also used should a transfer job end abnormally. It declares the end of job. All movement of the involved mechanisms shall have ceased before this message is sent. This message shall provide information on the success or failure of the transfer.

Transfer Job Started — This message marks the beginning of the transfer job. It signifies that the setup activities for the first atomic transfer are beginning.

Get Attribute — The host may request information relating to a specific job. This may include portions of the transfer specification and current status information.

4.2.1.2 *Macro Level Information Messaging* — There are a number of material transfer-related events which may be of significance to the host. These are designated as 'collection events' and shall be available for reporting to the host. This section describes those collection events and shows how they fit into the chronology of a transfer job. Refer to Figure 5 as each event is described.

Collection event messages provide valuable information to the host, but are not strictly required to perform material movement. Therefore, it is expected that some message protocol implementations will provide a method by which the factory host may disable those events which are not needed in a particular implementation.

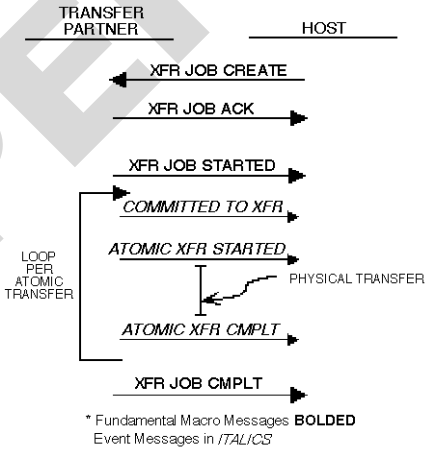

Figure 5
Macro Level Messaging With Events

Committed To Transfer — The equipment informs the host when it is fully prepared for a specific atomic transfer. This signifies the completion of the setup activities. It does not indicate that the two transfer partners have agreed to begin the physical handoff. This event coincides with the 'Transfer Ready' message defined in the micro level (see § 5 below).

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Atomic Transfer Started — The transfer partners inform the host, via an event, when the atomic transfer has begun.[6] This may represent a logical start rather than physical movement. This indicates that any necessary coordination of the transfer partners has been done to ensure that the atomic transfer may start. A secondary partner may sense the start of transfer later than the primary partner.

NOTE 3: The physical transfer begins following the Atomic Transfer Started event and ends prior to the Atomic Transfer Complete event message.

Atomic Transfer Complete — This event indicates that an atomic transfer has completed. This indicates that either the next atomic transfer for this port will begin the setup phase, or, if none remain, restore activities may begin.

4.2.2 *Transfer Job State Model* — Message flow diagrams are useful to show simple situations. Material movement may range from very simple to quite complex. The transfer job state model presented in this section provides the information necessary to extrapolate the message flow diagrams above to fit all situations within the scope of this report. It does not cover the states of the various hardware which may exist (e.g., elevators, doors). See § A1-1 for a discussion of the port hardware and related mechanisms.

The state model notation used in this report is that defined by Harel and is described in a reference cited in § 1.3 above.

The transfer job is a transient entity. It is created by the host (Transfer Job Create message), executes, and then is dissolved by the equipment.

Figure 6 shows a basic state diagram for a transfer job. The ovals at top and bottom show where the job is created and then deleted. The portion between the ovals is standard Harel notation. This model is from an equipment view and assumes that only one port on the equipment is used by the transfer. It also assumes that pause, resume, abort, and stop activities do not exist (these are addressed later in the Document).

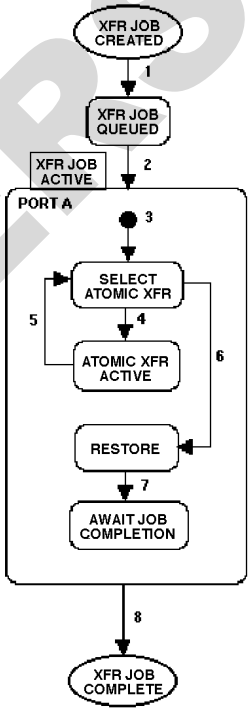

Figure 6
Transfer Job State Diagram for a Single Port

[6] The primary transfer partner will determine readiness to start based on micro level handshaking with the secondary transfer partner.

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State definitions and then the state transition table follow.

TRANSFER JOB QUEUED

In this state, the transfer job has been accepted by the equipment through the Transfer Job Create/Acknowledge messages and is awaiting execution. Transfer jobs are begun sequentially in the order received by the equipment. Execution may not begin until all previously queued transfer jobs have been started and the material locations needed for this transfer job may be allocated.

All transfer jobs pass through this state. If the equipment allows queuing of transfer jobs, they may remain in this state for prolonged periods. A transfer job remains queued until the material locations needed for that transfer are available.

TRANSFER JOB ACTIVE

In the TRANSFER JOB ACTIVE state, all atomic transfers defined in the transfer job are performed.

PORT A

This substate of TRANSFER JOB ACTIVE encloses the job activities related to a single port on the equipment. Within this state, the atomic transfers involving this port are executed sequentially (except as noted in § 4.1.7 under Atomic Transfer Sequencing Guidelines). Substates of PORT A (or PORT B, etc.) include SELECT ATOMIC TRANSFER, ATOMIC TRANSFER ACTIVE, RESTORE, and AWAIT JOB COMPLETION.

SELECT ATOMIC TRANSFER

In this state, the next atomic transfer for this port is selected. Any prerequisites for the atomic transfer are checked (e.g., is material XYZ in Port A, Location 1). Atomic transfers are executed sequentially per port (except as noted in § 4.1.7 under Atomic Transfer Sequencing Guidelines).

Prior to exiting this state, the port resources for the selected atomic transfer are allocated.

If no atomic transfer is ready for selection (e.g., the port resources are not available), the transfer job shall remain in this state, awaiting a change in conditions which would allow an atomic transfer to be selected.

ATOMIC TRANSFER ACTIVE

In this state, the next atomic transfer for this port is executed. See the atomic transfer state model for details on this process.

RESTORE

While in the RESTORE substate, the equipment shall perform any necessary post-transfer operations to return the port to the desired idle condition. These tend to be physical activities. No physical actions are required for restore, but some mechanism for determining port status is recommended.

The setup[7] and restore operations are expected to be 'goal oriented,' that is, oriented toward satisfying specific conditions (e.g., states such as 'door open'). They should not depend on a fixed sequence of actions such as 'initiate the door opening mechanism.' Thus, a port left in a post-transfer condition from a previous atomic transfer would still be able to prepare properly for the next.

When queuing is allowed, the equipment may provide a look ahead capability so it may alter its restore phase to better accommodate the next transfer job. Such functionality is not required.

AWAIT JOB COMPLETION

In this substate, all atomic transfers on this port for the transfer job have completed. The transfer job continues to exist until all ports have completed their atomic transfers and restore operations. If only one port is used, this state will be occupied only briefly.

The following transition table defines the transitions between states for the transfer job state model. It applies to Figures 6 and 7.

[7] Setup is more fully described in § 4.2.3.

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