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APPENDIX

APPENDIX

APPENDIX A

Cyclone Fence and Conveyor Belt Fabrication (Firm A)

COMMENTS TO APPENDIX A

The some 30 roles analyzed in the present study are discussed in considerable detail under their appropriate departments. The analysis of each role is presented in a format that generally agrees with the formal data acquisition procedure outlined above. The descriptions of role content, individual physical processes involved and the product flow through the three departments studied (see Table A-1) should provide for a detailed picture of the overall system and its various component systems structure and function.

The $T^{k}_{\ell..min} = \min_{(m)} \{T^{km}_{\ell..}\}$, $T^{k}_{\ell..max} = \max_{(m)} \{T^{km}_{\ell..}\}$ and $\bar{T}^{k}_{\ell..} = \frac{1}{M^{k}_{\ell..}} \sum_{m=1}^{M^{k}_{\ell..}} T^{km}_{\ell..}$, where the index set $M^{k}_{\ell..} = \{1,\ldots,m,\ldots,M^{k}_{\ell..}\}$ corresponds to the analysis interval of specified length $T_{\ell..}$, are given for most k, roles and for $\ell = 1,2$ (no detailed analysis is presented for r_3). The $T^{km}_{\ell..}$ are only given explicitly for those k,ℓ and roles for which $T^{km}_{\ell..}$ = constant for all $m \in M^{k}_{\ell..}$. The $t^{km}_{a\ell..}$ and $t^{km}_{t\ell..}$ for several tasks and roles are indicated. The type of and way in which quality standards are set are indicated very generally (specific quality standards needed not be determined since all roles studied were multi-task).

All the quotations appearing throughout the appendix are those of the supervisors talking to the interviewer or to their subordinates. These are presented as transcribed from recording tape used during the interviews with some modifications agreed to by the supervisors after having read and had the opportunity to amend the appendix.

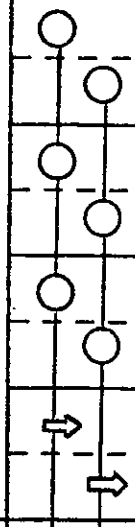
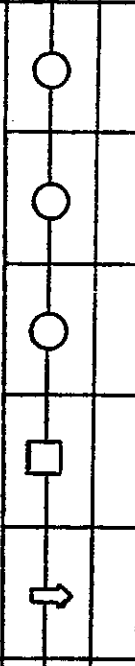
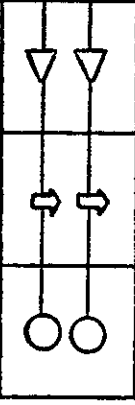
	Events	Description of Events	Operators	Equipment used
Weaving Department		Wire fed into weaving process	m/c Operator Mechanic	Chainlink m/c intake
		Wire and redwood slats fed into weaving process	m/c Operator	Rustake m/c
		Weaving operation performed (wire is woven into fabric)	m/c Operator Mechanic	Chainlink m/c
			m/c, Operator	Rustake m/c
		Woven fabric tied up in rolls	m/c Operator Mechanic	Chainlink m/c takeup
			m/c Operator	Rustake m/c
		Rolls transported to galvanizing department	m/c Operator Mechanic	Handtruck
		Rolls transported to storage area	m/c Operator	Handtruck
Galvanizing Department		Rolls fed into galvanizing process	Head Galvanizer	Pickle line
		Fabric is pickled and galvanized	Head Galvanizer Galvanizers (2)	Pickle line Galvanizing line
		Galvanized fabric tied up into rolls	Galvanizers (2)	Galvanizing line takeup
		Galvanized fabric tested for coating weight & tensile strength(@25/50 rolls)	Layout Draftsman	Tensile tester Balance
		Galvanized rolls transported to storage area	Galvanizers (2)	Fork-lift tractor
Warehouse and Shipping Department		Rolls stored for shipping		
		Rolls transported to loading ramp	Shipper Loaders	Fork-lift tractor
		Rolls loaded onto truck (train)	Shipper Loaders Shipping Clerk	Fork-lift tractor Handtrucks

TABLE A-1: PROCESS FLOW CHART OF WEAVING, GALVANIZING AND SHIPPING SYSTEMS.

WEAVING

Process Description

The weaving department contains four chainlink machines and one rustake machine. The chainlink machines produce cyclone fence (chainlink fence) of widths 2 ft.-12 ft. and meshes (diamond sizes) $1\frac{3}{4}$" x $1\frac{3}{4}$", 2" x 2" and 1" x 1" from ungalvanized steel wire of gages 6, 9, and 11 and of different tensile strengths. Some 10,000 ft. of chainlink fence may be produced on the chainlink machines during one shift.

As is indicated in Figure A-1, the steel wire is fed through a die and rotating arbor which forms the picket that is rotating and is woven into the last picket of the completed fabric. When this picket reaches its preset length, the wire is cut, the completed portion of the fabric progresses half-a-picket width, the last two barbs on each side of the fabric are bent (if knuckles are desired), and the next picket is being produced. This cycle is repeated until the predetermined number of pickets going into a complete roll is reached at which time a green light goes on. This number of pickets, which depends on the length of fabric going into a roll, the diamond size and wire gage, is preset on an electronic counter. All the above operations are performed automatically.

When the last picket required for a roll has been made, the counter resets and the operator then pulls out the picket immediately following the last one of the completed roll (this picket has no knuckles) when a few feet of the fabric going into the next roll have been produced. Then the operator ties up and removes the completed roll and starts the next one.

The rustake machine operates on a very similar principle. Its material input consists of galvanized steel wire and redwood slats.

These slats, which have been cut to the length of the fabric width, are stacked horizontally in a slat inserter running perpendicularly to the sides of the moving fabric one side of which barely clears the slat inserter. When two pickets have been produced and the fabric has progressed one diamond width, two redwood slats are automatically pushed through the pickets. This cycle is then continuously repeated.

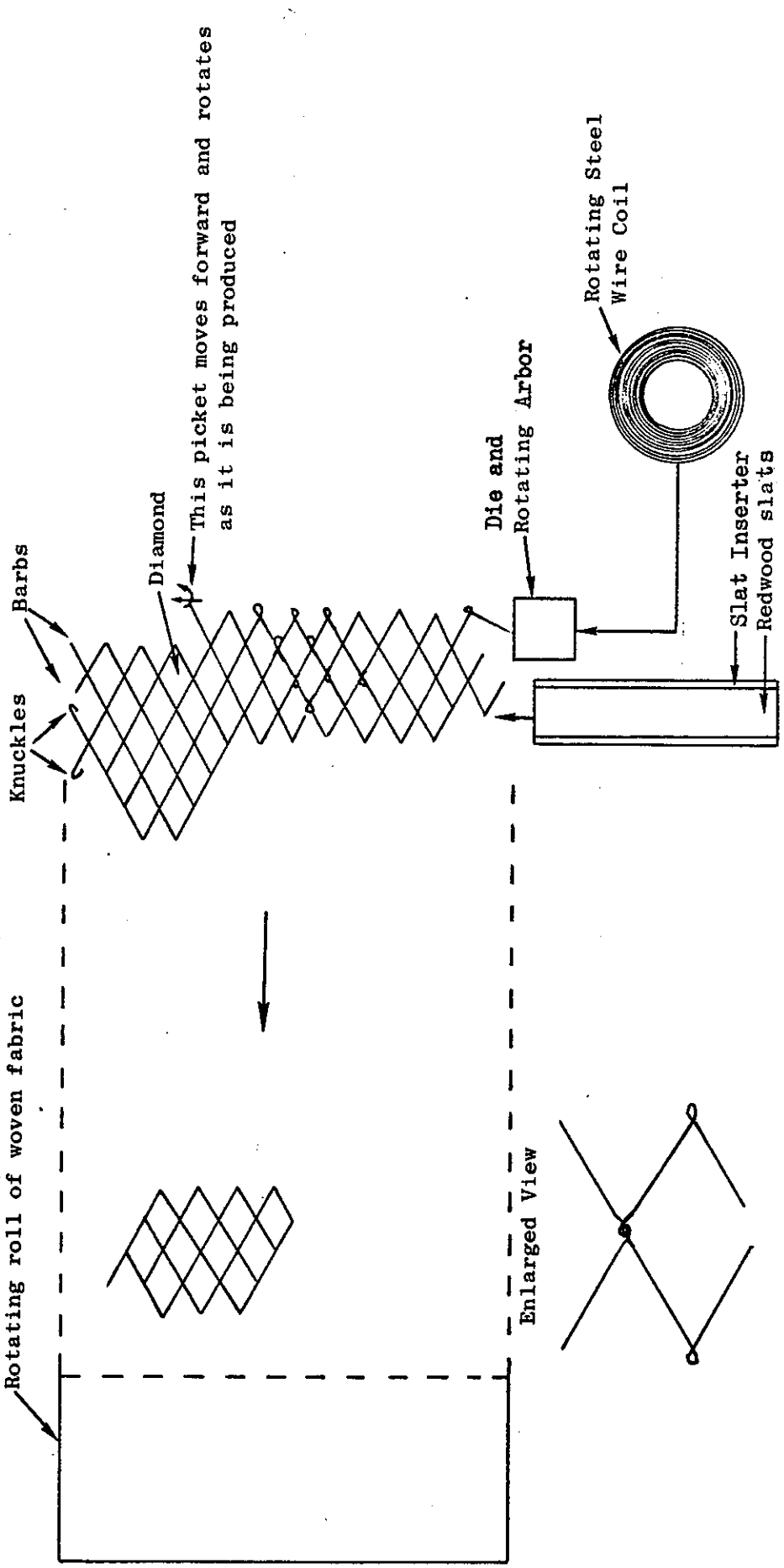


FIGURE A-1: SIMPLIFIED DIAGRAM OF THE WEAVING PROCESS (Top View)

1. Role Title: Foreman (Fence & Gate Fabrication), r_{21}
2. Immediate Superior: Superintendent, rI_3
3. Role Type: Multi-task
4. $\hat{L}_{21}$=3 months
5. Summary Table:

Task Set $\{S_{21}^k\}$	T_{21}^{km} T_{21min}^k = $=\overline{T}_{21}^k = T_{21max}^k$	Task Type: Continuous (c) Intermittent (i)
S_{21}^1 = analyzes and reports on safety (housekeeping & safety devices)	1 week	i
S_{21}^2 = analyzes and reports on safety (tools)	1 month	i
S_{21}^3 = makes safety contacts with subordinates	1 week	i
S_{21}^4 = analyzes and reports on safe job procedures	1 month	i
S_{21}^5 = prepares cost forecasts (tools, supplies, etc.)	2 weeks	i
S_{21}^6 = undertakes special projects	3 months *	i
S_{21}^7 = supervises subordinate production systems	1 month	i
S_{21}^8 = trains subordinate	4 days	i

* T_{21min}^6 = 1 day, $\overline{T}_{21}^6$ = 1 month, T_{21max}^6 = 3 months.

I. Role Content

This foreman rI_{21} plans, controls and monitors the operations of a system consisting of some twenty subordinates distributed over two shifts and the four departments of weaving, galvanizing, gate fabrica-

tion and fittings (see organization chart in Fig. 9). His production oriented planning function is concerned with determining the operating schedules for the individual departments and their role incumbents for each production order (the scheduling of the galvanizing process is done in cooperation with rI_{23}). Another output quantity of this planning system is the quality requirements of the individual physical outputs. For each production order, the planning system input is information obtained from the sales department regarding promised delivery date and product specifications (the product specifications as given in the sales order are generally interpreted by the layout draftsman rI_{146} and translated into a production order). His control and feedback monitoring function is then designed to ensure that the individual production plans are being adhered to.

He checks and analyzes the safety conditions of his operations regarding housekeeping and safety devices, tools and job procedures. His findings are periodically reported to rI_3 in written form. As an additional element in this safety program, he has to meet with his subordinates in small groups and discuss various potential hazards and how to handle different accidents through first-aid treatments, etc.

He also has to make biweekly cost forecasts for tools, supplies, maintenance and overtime. These forecasts, which represent his own estimates, are based on past data and anticipated expenses for the prediction period. The forecasts are reported on standard forms, of which rI_3 receives one copy; the first two of the above cost categories are reported on a separate form from the latter two as these categories belong to two separate cost centers in the company's cost control system.

A considerable amount of rI_{21}'s time is devoted to special projects involving redesigning the plant layout, improving various operations, etc. He may be involved in more than one such project simultaneously.

The training of new subordinates is also an activity of this role. At the time the TSD analysis was made, rI_{21} was responsible for training an individual to become an operator on the rustake machine.

II. Task Set

The tasks identified are listed in the above table. Their timing standards are generally explicitly set. For $S_{21}^{1},\ldots,S_{21}^{5}$, these are clearly set in the sense that the associated results have to be reported to rI_{3} at constant time intervals during which rI_{21} has to attend to these tasks. For S_{21}^{8}, the targeted completion instant is mutually agreed upon by rI_{21} and rI_{3}.

For S_{21}^{6}, however, the situation is more complex. rI_{21} is often allocated certain projects for which there are no definite targeted completion points either implicitly or explicity set by rI_{3}. Such indeterminate projects are mainly of the nature that "I would like you to do some thinking about this and tell me if you should come up with some ideas". Such projects may also be very indefinite as to the nature of its expected or hoped for results. Thus, for example, some aspect of a physical operation such as the chainlink-weaving operation may appear to be sub-optimal and rI_{3} would like rI_{21} to look into this and see if any improvements could be made. rI_{3} may have no idea in mind and would even accept an outcome of this investigation concluding that no such process improvement appears feasible assuming that

rI_{21} has demonstrated to rI_3 that he has sufficiently explored the situation.

For such indefinite projects it was found, however, that some phases or sub-projects frequently did have ascertainable targeted completion points. Furthermore, entire projects of a more definite nature are also frequently allocated to rI_{21} as, for example, carrying out some safety recommendations.

The quality standards for $S_{21}^1,\ldots,S_{21}^6,S_{21}^8$ are implicitly set in terms of the degree of detailing for the analyses and reports associated with $S_{21}^1,\ldots,S_{21}^4$; of prediction accuracy for S_{21}^5; of the degree of thoroughness, sophistication, etc. for S_{21}^6; and of the level of independent job performance by the new operator upon the completion of S_{21}^8.

The relatively complex task S_{21}^7 warrants some detailed comments. It incorporates the planning and feedback control operation of rI_{21} for each production order. The individual S_{21}^{7m} are not directly allocated by rI_3 but rather their inputs originate with the sales department. rI_3 may only possess very general information about the individual production orders. In Jaques' terminology, the S_{21}^{7m} are generated by "general responsibilities" (see, eg., [26], p. 8).

Aggregate plans are maintained for about 1 month ahead of time and rI_{21} revises and modifies them once a week. The primary objectives of these plans and the associated control functions of rI_{21} are to ensure that the different production orders a) are completed sufficiently early to meet the promised delivery dates (a reasonable time also has to be allowed for the shipping process, see TSD analysis of rI_{23}), b) meet customer specifications and c) utilize available re-

sources (capital equipment, manpower, services, operating supplies, etc.) while not requiring excessive resource commitments. Regarding these three task requirements, the following appears to be the case:

1) Only if a production order was delivered considerably behind the promised delivery time would rI_3 certainly receive customer feedback to this effect. If, however, rI_{21} did not properly allow for handling and shipping time, rI_{23} may compensate for this by "emergency" procedures of which rI_3 may not become explicitly aware unless significant extra costs were incurred.

2) If a completed order does not meet customer specifications, this cannot really be attributed to the continuous exercise of marginally substandard discretion by rI_{21} but rather as a gross error made by him. This may occur through faulty specifying and by rI_{21} wrongly perceiving the specifications or communicating them incorrectly to his subordinates.

3) For each of his production departments, rI_{21} is given prescribed limits on total resource deployment for each month. These standards are used by rI_3 to evaluate the monthly overall performance quality of S^7_{21}. For the chainlink-fence operation, for example, standard monthly performance is to produce x lbs. of fabric (for the gate fabrication operation, no such standard for production volume exists) while using $y for maintenance, $z for operating supplies, t hrs. of overtime, etc. during a month. These standard figures and the corresponding actual figures for one month, which are prepared by the accounting department, are given to rI_3 at the beginning of the next month. Both rI_3 and rI_{21} know these standard figures for a month at the beginning of

that month. If rI_{21} had continuously performed S_{21}^{7} marginally substandardly during a month, this would be detected by rI_{3} through this monthly production and cost statement.

III. Role Type

r_{21} is clearly multi-task since $I_{21}^{km} \cap I_{21}^{k'm'} \neq \emptyset$ for $(k,k') = (1,2), (2,3), (1,4),\ldots,(1,6), (3,8),\ldots$, and for at least one (m,m') if $T_{21} = 2$ years.

IV. TSD Set and LOW

The reports associated with S_{21}^{1} and S_{21}^{3} are weekly and those associated with S_{21}^{2} and S_{21}^{4} are monthly so it follows from the above that $T_{21}^{1m} = T_{21}^{3m} = 1$ week, $T_{21}^{2m} = T_{21}^{4m} = 1$ month for all m.

One set of cost forecasts covering all of month x has to be completed by the end of month x-1; another set of forecasts has to be completed by the middle of month x covering the remainder of that month. Throughout the time period between two consecutive reporting instants, rI_{21} has to try and accumulate information for making as reliable predictions as possible. Thus, $T_{21}^{5m} = 2$ weeks for all m.

rI_{21} and rI_{3} may frequently discuss the various projects that rI_{21} is involved in. These discussions, which may be held during informal and formally scheduled meetings, are generally concerned with certain aspects of a project and often those aspects that a) are closely related to other projects assigned to one or more of the other foremen, b) are preliminary to the main project, c) involve a relatively high rate of resource deployment, and d) rI_{3} (and/or rI_{21}'s supervisor once removed) is particularly interested in. These meetings are most frequently of the nature of intermediate progress reviews rather than "complete" re-

views as defined previously. When considering timing reviews occurring at the targeted completion points for assigned projects, it was found that T^6_{21min} = 1 day, $\overline{T}^6_{21}$ = 1 month and T^6_{21max} = 3 months.

The on-the-job training of a new swing-shift operator on the rus-take machine lasted only for four days after which time this operator was capable of performing his work quite satisfactorily. This operator had had a considerable amount of previous experience in operating a fairly similar type of machine which accounted for the very short training period required. During this period, the regular day-shift operator was transferred to the swing shift so that the trainee could be assisted by rI_{111} and his progress intermittently reviewed by rI_{21}. The length of this training period agreed with what rI_3 had initially prescribed so that clearly T^8_{21max} = 4 days. If this person had been barely acceptable as a new trainee by rI_3, then rI_3 would have allowed rI_{21} 2 months for bringing this trainee up to the minimum acceptable performance level.

If the resource deployment review interval of section #II above is considered to determine the TSD of the composite task S^7_{21}, then T^7_{21} = 1 month. From the above it now follows that $\hat{L}_{21} \triangleq \max_{(k)} \{T^k_{21max}\}$ = = 3 months.

1. Role Title: Mechanic, r_{111}
2. Immediate Superior: Foreman (Fence & Gate Fabrication), rI_{21}
3. Role Type: Multi-task
4. $\hat{L}_{111}$ = 4 days
5. Summary Table:

Task Set $\{S^k_{111}\}$	T^{km}_{111}			Task Type: Continuous (c) Intermittent (i)
	T^k_{111min}	$\bar{T}^k_{111}$	T^k_{111max}	
S^1_{111} = operates weaving machines	½ hr.	6 hrs.	1 day	i
S^2_{111} = transports rolls to galv. dept.	½ hr.	6 hrs.	1 day	i
S^3_{111} = lubricates machines, etc.	1 hr.	1 hr.	1 hr.	c
$S^4_{11.1}$ = repairs machines	5 min.	½ hr.	1 day	i
S^5_{111} = sets up machines for product change	5 min.	20 min	2 hrs.	i
S^6_{111} = trains operator	4 days	4 days	4 days	i

I. Role Content

The mechanic rI_{111} operates two weaving (chainlink) machines, which involves rolling up the woven fabric (see above process descriptions) and monitoring the process performance, taking corrective actions whenever necessary. The monitoring activity is concerned with checking that the machines do not miss knuckles and that the wire does not get tangled up or break. Whenever knuckles are missed, rI_{111} has to bend these barbs using a pair of pliers. If there is tangling or breaking of the wire, the machine automatically stops and he has to reset it,

rethread some of the fabric by hand and restart the machine.

He also transports the completed rolls to the galvanizing department using a handtruck. He lubricates all the machines during one hour prior to the day-shift operation. Repairs and set-up changes are all made by rI_{111}. He repairs one machine while still operating another one. If one of the two machines operated by the machine operator rI_{112} breaks down, rI_{112} takes over the operation of the machines attended to by rI_{111} while the latter repairs the faulty machine and operates the one next to it. When the correction has been made, they change back to their own machines again. The same procedure takes place when rI_{111} is resetting a machine for a new production run with different product specifications.

At the time the TSD analysis was made, rI_{111} had just completed the training of a new operator for the rustake machine. This operator had had some previous experience in operating a comparable machine so that rI_{111} was mainly assisting and advising him.

II. Task Set

The various tasks identified for rI_{111} are listed in the above table. The timing standards for S^1_{111}, S^2_{111} and to some extent S^5_{111} are explicitly given in the production schedule. These standards for S^3_{111} (see above role-content analysis) and S^6_{111} (see the TSD analysis of rI_{21}) are also explicitly set whereas those for S^4_{111} were found to be implicitly set and generally ascertainable. "Many of the breakdowns are of similar nature and we both have a pretty good idea of how long it ought to take to do the repairs."

The quality standards for most of these tasks are based on intuitive understandings between rI_{111} and rI_{21}. Only for S^6_{111} are these

standards made explicit, e.g. "I want you to make sure that this new guy will be able to work on his own (at a certain performance level) when he is through with the training". For $S^1_{111},\ldots,S^5_{111}$, these standards are generally set in terms of neatness, maintaining production delays due to breakage of wire below some level, performing repairs so as to achieve a certain minimum equipment reliability, etc.

III. Role Type

r_{111} is multi-task since $t^{1m}_{a111} = t^{2m}_{a111}$ for all m and $I^{km}_{111} \cap I^{k'm'}_{111} \neq \emptyset$ for $(k,k') = (1,4),\ldots,(2,6),\ldots,(1,1),\ldots$, and for more than one (m,m') if $T_{111} = \frac{1}{2}$ year.

IV. TSD Set and LOW

From the above it follows that $T^{3m}_{111} = 1$ hr. for all m and $T^{61}_{111} = 4$ days (S^6_{111} was performed only once during the interval T_{111}. It was also found that $T^5_{111max} = 2$ hrs. and $T^4_{111max} = 1$ day. If a repair job is quite lengthy, then one or more maintenance mechanics $rI_{14j}(j=1,2,3)$ may be assigned to work on it together with rI_{111}. The maintenance mechanic rI_{145} on the swing shift will also do some work on this if it is not completed during the day shift.

Some of the production orders may take up to a month to complete; however, any production run that is not completed by rI_{111} during the day shift is also worked on by his swing-shift replacement. Furthermore, the same arguments as those given below regarding the $rI_{14j}(j=1,2,3)$ also apply here with some obvious modifications, so that $T^k_{111max} = 1$ day for $k = 1,2$. T^k_{111min} and $\overline{T}^k_{111}$ obtained for $k = 1,\ldots,6$ are given in the above table. Thus, $\hat{L}_{111} \triangleq \max_{(k)} \{T^k_{111max}\} = 4$ days.

1. Role Title: Machine Operator (Chainlink Machine), r_{11j} (j=2 for day-shift; j=3,4 for swing-shift)*
2. Immediate Superior: Foreman (Fence & Gate Fabrication), rI_{21}
3. Role Type: Multi-task
4. $\hat{L}_{11j}$ = 1 day for j=2,3,4
5. Summary Table:

	Task Set $\{S^k_{11j}\}$	T^{km}_{11j}			Task Type: Continuous (c) Intermittent (i)
		T^k_{11jmin}	$\bar{T}^k_{11j}$	T^k_{11jmax}	
j=2	S^1_{11j} = operates weaving machines	½ hr.	6 hrs.	1 day	i
	S^2_{11j} = transports rolls to galv. dept.	½ hr.	6 hrs.	1 day	i
j=3,4	S^1_{11j} = operates weaving machines	1 day	1 day	1 day	i
	S^2_{11j} = transports rolls to galv. dept.	1 day	1 day	1 day	i

I. Role Content

This machine operator rI_{112} operates two chainlink machines as does the mechanic rI_{111}, the difference in role content between the two being that the former does not contain tasks analogous to the latter's $S^3_{111},\ldots,S^6_{111}$.

II. Task Set

The tasks of r_{112}, which are listed in the above table, have timing

* The subsequent analysis refers particularly to rI_{112}, see # V below for rI_{11j} (j=3,4).

and quality standards similarly set to those for the same tasks of r_{111}.

III. Role Type

r_{112} is multi-task since $t_{a112}^{1m} = t_{a112}^{2m}$ for all m and $I_{112}^{km} \cap I_{112}^{k'm'} \neq \emptyset$ for $(k,k') = (1,1), (1,2), (2,2)$ and for more than one (m,m') if $T_{11j} = \frac{1}{2}$ year.

IV. TSD Set and LOW

Since the comments regarding $T_{111max}^{k}(k=1,2)$ also apply to $T_{112max}^{k}(k=1,2)$, it was found that $T_{112max}^{k} = 1$ day for $k = 1,2$. T_{112min}^{k} and $\bar{T}_{112}^{k}$ obtained for $k = 1,2$ are given in the above table. Thus, $\hat{L}_{112} \triangleq \max_{(k)} \{ T_{112max}^{k} \} = 1$ day.

V. Comments

The preceding analysis refers particularly to the day-shift operator rI_{112}. The only difference between rI_{112} and the two swing-shift operators rI_{113} and rI_{114} is that for the latter $T_{11jmin}^{k} = \bar{T}_{11j}^{k} = T_{11jmax}^{k} = 1$ day for $k = 1,2$ and $j = 3,4$. This is so since product specification changes are not scheduled for the swing shift. Thus, $\hat{L}_{113} = \hat{L}_{114} = 1$ day.

1. Role Title: Machine Operator (Rustake Machine),

r_{11j} (j=5 for day shift; j=6 for swing shift)*

2. Immediate Superior: Foreman (Fence & Gate Fabrication), rI_{21}

3. Role Type: Multi-task

4. $\hat{L}_{115}$ = 1 day

5. Summary Table:

Task Set $\{S^k_{11j}\}$	T^{km}_{11j}			Task Type: Continuous (c) Intermittent (i)
	T^k_{11jmin}	$\bar{T}^k_{11j}$	T^k_{11jmax}	
S^1_{115} = operates rustake machine	1 hr.	7 hrs.	1 day	i
S^2_{115} = transports rolls to storage area	1 hr.	7 hrs.	1 day	i
S^1_{116} = operates rustake machine	1 day	1 day	1 day	i
S^2_{116} = transports rolls to storage area	1 day	1 day	1 day	i

I. Role Content

This machine operator rI_{115} on the rustake machine performs comparable type work to that of the operator rI_{112} on the chainlink machines (see also above process description).

II. Task Set

The tasks of r_{115}, which are listed in the above table, have

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* The subsequent analysis refers particularly to rI_{115}, see # V below for rI_{116}.

timing and quality standards similarly set to those for the same tasks of r_{111}.

III. Role Type

r_{115} is multi-task since $t^{1m}_{a115} = t^{2m}_{a115}$ for all m.

IV. TSD Set and LOW

For $T_{115} = \frac{1}{2}$ year, and since the comments regarding $T^{k}_{111max}(k=1,2)$ also apply to the $T^{k}_{115\ max}$, it was found that $T^{1}_{115max} = T^{2}_{115max} = 1$ day. T^{k}_{115min} and $\overline{T}^{k}_{115}$ obtained for k = 1,2 are given in the above table. Thus, $\hat{L}_{115} \triangleq \max_{(k)} \{ T^{k}_{115max} \} = 1$ day.

V. Comments

The preceding analysis refers particularly to the day-shift operator rI_{115}. The only difference between rI_{115} and the swing-shift operator rI_{116} is that for the latter $T^{k}_{116min} = \overline{T}^{k}_{116} = T^{k}_{116max} = 1$ day for k = 1,2. This is so since product specification changes are not scheduled for the swing shift. Thus, $\hat{L}_{116} = 1$ day.

GALVANIZING

Process Description

The material input to the galvanizing process, which are rolls of cyclone fence (chainlink fence, woven fabric) produced in the plant's weaving department, is unrolled and continuously fed through the pickle and galvanizing lines as illustrated in Figure A-2. The end of one roll passing through the process is manually tied to the beginning of the next roll. The pickle line consists of three steam-heated consecutive tanks containing muriatic acid, water and preflux through which the fabric is cleaned as it passes through prior to entering the galvanizing line. This line, besides containing rollers for moving the fabric, consists mainly of the zinc kettle. The kettle contains molten zinc at 865°F mixed with an aluminum compound and some charcoal on the zinc surfaces.

The coating weight of the final product, i.e., the number of ounces of zinc per square foot of wire surface, which is either 1.2, 2.0 or 2.4, is determined by the length of time that the fabric remains immersed in the zinc bath and its temperature. This in turn is controlled by the speed at which the fabric moves through the line as well as by how deep into the kettle it goes.

The galvanized fabric emerging from the zinc kettle then enters the take-up stage where it is rolled up mechanically. The end of the roll is manually tied up, the roll is removed and the next one is being rolled up.

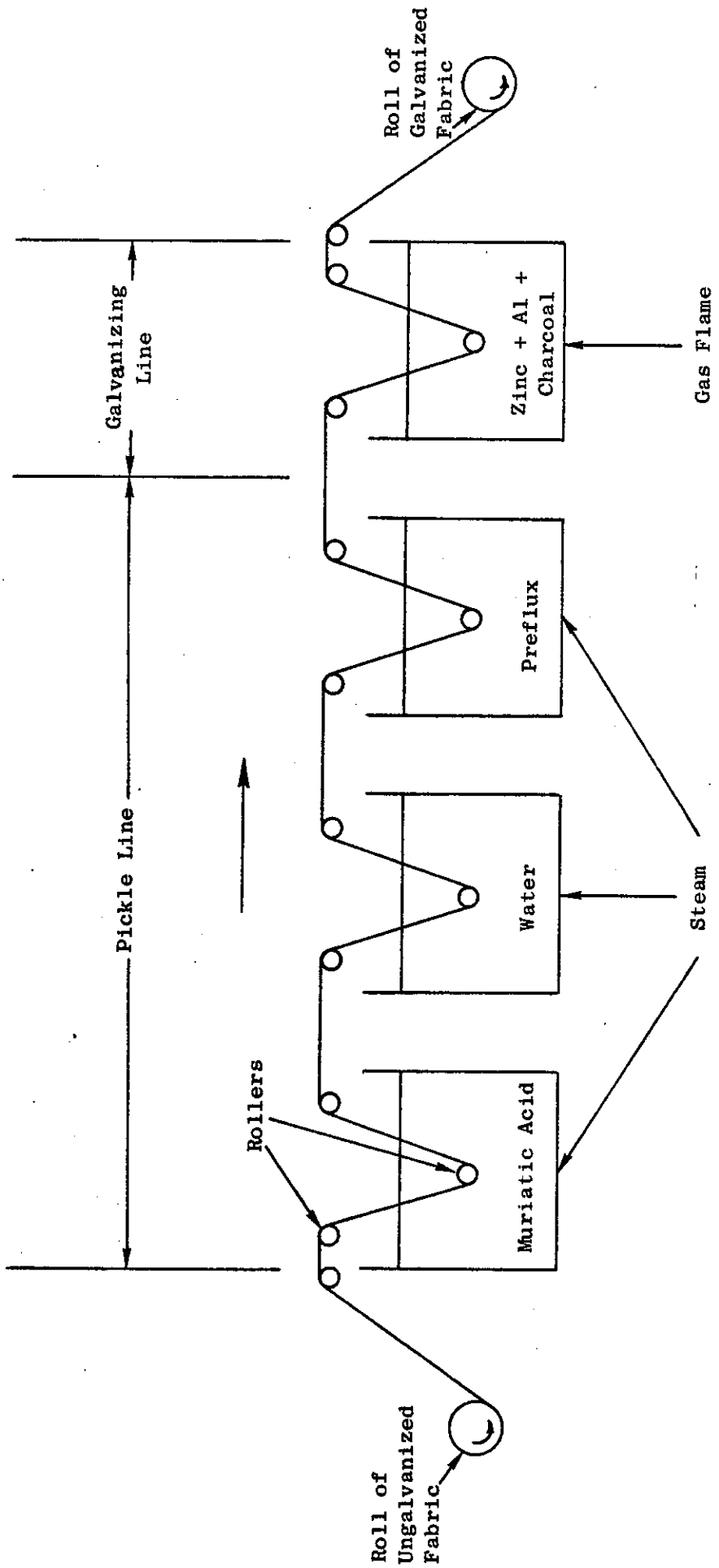

FIGURE A-2: SIMPLIFIED DIAGRAM OF THE GALVANIZING PROCESS

1. Role Title: Head Galvanizer,

r_{11j} (j=7 for day shift; j=8 for swing shift)*

2. Immediate Superior: Foreman (Fence & Gate Fabrication), rI_{21}

3. Role Type: Multi-task

4. $\hat{L}_{117} = \hat{L}_{118} = 1$ day

5. Summary Table:

Task Set $\{S^k_{11j}\}$	T^{km}_{11j}			Task Type: Continuous (c) Intermittent (i)
	T^k_{11jmin}	$\bar{T}^k_{11j}$	T^k_{11jmax}	
S^1_{117} = starts up galvanizing process	1 hr.	1 hr.	1 hr.	c
S^2_{117} = operates galvanizing process	½ hr.	6 hrs.	1 day	i
S^3_{117} = feeds lines with fabric	½ hr.	6 hrs.	1 day	i
S^4_{117} = sets up process for product specification changes	5 min.	15 min.	½ hr.	c
S^1_{118} = operates galvanizing process	1 day	1 day	1 day	i
S^2_{118} = feeds lines with fabric	1 day	1 day	1 day	i

I. Role Content

The head galvanizer rI_{117} on the day shift arrives at work one hour earlier than the rest of the galvanizing crew in order to start up the

* The subsequent analysis refers particularly to rI_{117}, see # V below for rI_{118}.

process. This involves adding zinc, charcoal and an aluminum compound to the zinc kettle and water, acid and preflux to the pickle line; he then sets the temperature of the kettle and starts the pickle and galvanizing lines.

Once the process is operating, he feeds it with fabric, moving rolls from "storage" (where left by weaving m/c operators) and tying the end of one roll going through the process to the beginning of the next one with wire. He is also responsible for monitoring the various process variables (e.g., speed of lines) and for making corrective actions whenever necessary. He similarly ensures that the fabric does not get tangled up anywhere in the process and that certain errors occurring in the weaving process, such as missing knuckles, are corrected.

When one production run is completed, he has to reset the appropriate process variables to handle the product specifications of the next production run, assuming these consecutive orders have different specifications.

II. Task Set

The tasks identified for r_{117} are listed in the above table. The timing standards for S^2_{117}, S^3_{117} and to some extent S^4_{117} are explicitly laid down in the production schedule (see IV below); the one for S^1_{117} is explicitly set as follows from the above role—content analysis.

The quality standards for $S^1_{117},\ldots,S^4_{117}$ are all based on mutual understandings between rI_{117} and rI_{21} and are such as to ensure that the overall quality requirements of the final product are met such as the prescribed coating weight and product finish. "He knows he has to

stay a bit above the required coating weight, but not too much. He also has to make sure that he catches tangling of the fabric soon enough so that it is not messing things up in terms of getting way too heavy a coating and slowing down the work."

III. Role Type

r_{117} is multi-task since $t_{a117}^{2m} = t_{a117}^{3m}$ for all m.

IV. TSD Set and LOW

From the above analysis of the role content it follows that $T_{117}^{1m} = 1$ hr. for all m. It was found that $T_{117max}^{4} = \frac{1}{2}$ hr.

Some of the production runs may last for several weeks, however, the swing-shift galvanizing crew is also working on these same long-term production orders. "It is clear to all these men how much work they have to do during each shift, they can see this from the production schedule they are given. At the end of the day shift I kind of check to see if they have kept pace with the schedule; of course I usually get some idea of this during the day when I often make casual checks. I will then discuss with the swing-shift people where we stand; I sometimes do this through my day-shift galvanizer. If, for example, the fabric is difficult to run, I may notice that the day-shift people are behind schedule, the reason may be that the head galvanizer has not been spending enough time on checking different things so that the fabric has gotten tangled up a lot. I will then tell the swing-shift man to be especially careful about this. The next morning I'll then check how the swing-shift people did and tell the day-shift people what to do, etc. I would definitely say that the people on both shifts have to kind of plan their work so that they are not behind the schedule at the

end of a shift."

Furthermore, if a production order was scheduled for completion within, say, one month, the head galvanizer (and also the galvanizers) on one of the shifts may continuously work marginally behind schedule without this causing the actual project completion to fall behind the scheduled one unless the persons on the other shift continuously performed at, below or marginally above the standards (see also [26], pp. 18-19, 48-49 regarding "waiting time").

For $T_{117} = \frac{1}{2}$ year, it was found that several production orders took more than a couple of shifts to galvanize. It then follows from the above that $T^2_{117max} = T^3_{117max} = 1$ day. T^k_{117min} and $\bar{T}^k_{117}$ obtained for $k = 1,\ldots,4$ are given in the above table. Thus, $\hat{L}_{117} \triangleq$ $\triangleq \max_{(k)} \{T^k_{117max}\} = 1$ day.

V. Comments

The swing-shift rI_{118} takes over the process while it is still in operation so that he needs not perform a task equivalent to S^1_{117}. Furthermore, since product specification changes are not scheduled for the swing shift, rI_{118} performs only the tasks S^1_{118} and S^2_{118} equivalent to S^2_{117} and S^3_{117} for which $T^k_{118min} = \bar{T}^k_{118} = T^k_{118max} = 1$ day for $k = 1,2$. Thus, $\hat{L}_{118} \triangleq 1$ day.

1. Role Title: Galvanizer,

   r_{11j}(j=9,10 for day shift; j=11,12 for swing shift)*

2. Immediate Superior: Foreman (Fence & Gate Fabrication), rI_{21}

3. Role Type: Multi-task

4. $\hat{L}_{11j}$ = 1 day for j=9,10,11,12

5. Summary Table:

	Task Set $\{S^k_{11j}\}$	T^{km}_{11j}			Task Type: Continuous (c) Intermittent (i)
		T^k_{11jmin}	$\bar{T}^k_{11j}$	T^k_{11jmax}	
j=9,10	S^1_{11j} = operates galv. process	½ hr.	6 hrs.	1 day	i
	S^2_{11j} = transports rolls to storage area	½ hr.	6 hrs.	1 day	i
	S^3_{11j} = sets up process for product specification changes	5 min.	15 min.	½ hr.	c
j=11,12	S^1_{11j} = operates galv. process	1 day	1 day	1 day	i
	S^2_{11j} = transports rolls to storage area	1 day	1 day	1 day	i

I. Role Content

The two galvanizers rI_{11j}(j=9,10) work together at the output end of the process tying up the galvanized rolls of fabric with wire, removing one finished role from the winding-up equipment while starting

* The subsequent analysis refers particularly to rI_{11j}(j=9,10), see # V below for rI_{11j}(j=11,12).

the next one. When a few of these rolls have been completed, they are transported by a fork-lift tractor to the storage area.

They also check the fabric as it emerges from the galvanizer to ensure that the finish is free from black spots caused by poor pickling and that the fabric does not get tangled up. Whenever they notice such spotting, they report it to the head galvanizer rI_{117} who then takes appropriate corrective action. If any tangling occurs, then the galvanizers attempt to correct it immediately to prevent that the fabric gets overcoated by staying too long in the kettle and that the lines have to be stopped. As for rI_{117}, another objective for their monitoring activity is to detect and correct possible faults in the fabric such as the occurrence of barbs instead of knuckles.

Between production runs the galvanizers have to reset their part of the process in accordance with changes in product specifications.

II. Task Set

The tasks of r_{11j}, which are listed in the above table, have timing standards that are explicitly laid down in the production schedule. Their quality standards are implicitly set (see rI_{117}). "They can only tolerate a minimum of spotting (black spots on fabric), i.e., x number of spots per ten feet of fabric, say. They have to get their end of the process set up for a new job in such a way that all is O.K. so that there will be no tangling because of these resettings,...",etc.

III. Role Type

r_{11j} is multi-task since $t^{1m}_{a11j} = t^{2m}_{a11j}$ for all m and for j = 9,10.

IV. TSD Set and LOW

Since the above comments regarding S^2_{117}, S^3_{117} and S^4_{117} also apply to the S^k_{11j} ($k=1,2,3$; $j=9,10$), it follows that $T^k_{11j\max} = 1$ day for $k = 1,2$ and $T^3_{11j\max} = \frac{1}{2}$ hr. for $j = 9,10$. $T^k_{11j\min}$ and $\overline{T}^k_{11j}$ obtained for $k = 1,2,3$ and $j = 9,10$ are given in the above table. Thus, $\hat{L}_{11j} \triangleq \max_{(k)} \{T^k_{11j\max}\} =$ $= 1$ day for $j = 9,10$.

V. Comments

Since product specification changes are not scheduled for the swing shift, the tasks performed by the rI_{11j} ($j=11,12$) are those listed in the above table for which $T^k_{11j\min} = \overline{T}^k_{11j} = T^k_{11j\max} = 1$ day for $k = 1,2$ and $j = 11,12$. Thus, $\hat{L}_{11j} = 1$ day for $j = 11,12$.

WAREHOUSE AND SHIPPING

Process Description

The warehouse and shipping department handles all the plant's incoming and outgoing material, maintains most of the plant's parts and material inventory and stores completed production orders awaiting shipment. This department also schedules shipments and orders the truck (train) service receiving frequent advice regarding shipping rates, etc. from the company's main traffic office located nearby. Some 300,000 lbs. of parts and material are shipped and an equal amount of parts and raw material (primarily wire) is received by this department per week.

Based on the detailed production orders (bills of material, tally sheets), the foreman of this department obtains all required information regarding the components needed for each order, the name and address of the customer and promised delivery date. On the basis of this information, the shipping foreman in consultation with the production foremen and the traffic office (through the purchasing agent and traffic clerk) schedules the shipments, arranges the transportation and assigns his crew to load all the parts and material.

All incoming deliveries of parts and material are checked against the purchase requisitions before accepting the shipment. If this arrives by truck (train), it is unloaded by the shipping crew and the parts and material are transported to various storage areas or directly to the person or department who ordered the shipment.

The equipment used for transporting parts and material from storage to the loading ramp and vice versa and for loading/unloading the trucks (trains) consists of fork-lift tractors with specially designed forks, handtrucks and buggies. A rotary crane is also occasionally used.

1. Role Title: Foreman (Warehouse & Shipping), r_{23}
2. Immediate Superior: Superintendent, rI_3
3. Role Type: Multi-task
4. $\hat{L}_{23}$ = 3 months
5. Summary Table:

Task Set $\{S_{23}^k\}$	T_{23}^{km}	Task Type: Continuous (c) Intermittent (i)
	$T_{23min}^k = \bar{T}_{23}^k = T_{23max}^k$	
S_{23}^1 = analyzes and reports on safety (housekeeping & safety devices)	1 week	i
S_{23}^2 = analyzes and reports on safety (tools)	1 month	i
S_{23}^3 = makes safety contacts with subordinates	1 week	i
S_{23}^4 = analyzes and reports on safe job procedures	1 month	i
S_{23}^5 = prepares cost forecasts (tools, supplies, etc.)	2 weeks	i
S_{23}^6 = undertakes special projects	3 months*	i
S_{23}^7 = supervises the warehouse & shipping operation	1 month	i

* T_{23min}^6 = 1 day, $\bar{T}_{23}^6$ = 1 month, T_{23max}^6 = 3 months.

I. Role Content

The general role content of r_{23} is quite similar to that of r_{21}. rI_{23}, however, was not responsible for training any new subordinates during the interval T_{23} of length 2 years. Thus, rI_{23} makes the same type of safety analyses, reports and contacts, cost forecasts and works

on various development projects as does rI_{21}. His general responsibility is the planning, monitoring and control of all the operations performed by his subsystem consisting of the plant's warehouse and shipping facilities and some seven subordinates distributed over two shifts. The planning function mainly entails scheduling the various shipments (and also the galvanizing process together with rI_{21}) based on information obtained from a) the bill of materials regarding the size (volume, weight and number of components) and destination of and promised delivery date for each shipment, b) the company's local traffic office regarding freight rates, etc. and c) the trucking and train lines regarding shipping routes and transportation times. rI_{23}'s feedback monitoring and control function is then designed to ensure that the individual shipping schedules are being met and that his available resources are being efficiently deployed (see also next section #II).

His department also handles all incoming parts and material so that rI_{23} has to integrate this into his planning, monitoring and control function.

II. Task Set

The tasks identified for r_{23} are given in the above table. The timing and quality standards for $S_{23}^1,\ldots,S_{23}^5$ are similarly set to those for the $S_{21}^k(k=1,\ldots,5)$. For S_{23}^6, the comments given for S_{21}^6 apply. rI_{23} and rI_{21} are, in fact, often assigned individual sub-projects of some master project. Thus, both rI_{23} and rI_{21} were given the responsibility of developing an improved scheme for removing fabric from the galvanizer. rI_{23} was mainly concerned with finding a better way to store the galvanized rolls so as to better utilize available storage space and to make it easier to pick up and transport the rolls to the

loading ramp. rI_{21} was mainly responsible for redesigning the process that rolls up the fabric and removes the rolls.

For S_{23}^{7}, the comments given for S_{21}^{7} also apply here to some extent. Thus, the planning and control functions associated with each incoming and outgoing shipment are generated by "general responsibilities" rather than direct supervisory task allocation. For the outgoing shipments the targeted completion times of the corresponding S_{23}^{7m} correspond to the promised delivery times. However, if rI_{23} caused a minor job for an "unimportant" customer to be delivered considerably behind the promised delivery time, this may never come to the attention of rI_{3}. Furthermore, rI_{3} exercises little or no control over the S_{23}^{7m} associated with incoming shipments and certainly no closed-loop control except for the aggregate control of the resource deployment variable as for the S_{21}^{7m}. As for rI_{21}, the supervisory sampling frequency for this variable is one sample per month.

III. Role Type

r_{23} is multi-task since $I_{23}^{km} \cap I_{23}^{k'm'} \neq \emptyset$ for $(k,k') = (1,2), (2,3), (1,4), \ldots, (1,6), (7,8), \ldots$ and for more than one (m,m') if $T_{23} = 2$ years.

IV. TSD Set and LOW

It follows from the preceding analysis that $T_{23}^{1m} = T_{23}^{3m} = 1$ week, $T_{23}^{2m} = T_{23}^{4m} = 1$ month and $T_{23}^{5m} = 2$ weeks for all m. If we consider the resource deployment review interval of #II above as determining the TSD of the composite task S_{23}^{7}, then $T_{23}^{7} = 1$ month. For S_{23}^{6}, it was found that $T_{23min}^{6} = 1$ day, $\bar{T}_{23}^{6} = 1$ month and $T_{23max}^{6} = 3$ months. Thus, $\hat{L}_{23} \triangleq \triangleq \max_{(k)} \{T_{23max}^{k}\} = 3$ months.

1. Role Title: Shipper, r_{131}
2. Immediate Superior: Foreman (Warehouse & Shipping), rI_{23}
3. Role Type: Multi-task
4. $\hat{L}_{131}$ = 1 day
5. Summary Table:

Task Set $\{S^k_{131}\}$	T^{km}_{131}			Task Type: Continuous (c) Intermittent (i)
	T^k_{131min}	$\bar{T}^k_{131}$	T^k_{131max}	
S^1_{131} = unloads incoming material	10 min.	2 hrs.	3 hrs.	c
S^2_{131} = loads outgoing material	10 min.	1 hr.	3 hrs.	i
S^3_{131} = transports material	10 min.	6 hrs.	1 day	i, c
S^4_{131} = supervises loading and transporting	10 min.	6 hrs.	1 day	i

I. Role Content

The shipper rI_{131} coordinates and to some degree directs the loading operation of outgoing material such as cyclone fence, gates, conveyor belts, etc. This involves getting all the material for each shipment assembled and loaded onto the truck (train) and instructing the loaders rI_{132} about what has to be loaded, according to information obtained from the foreman rI_{23} and the bill of materials, and about how to distribute the load on the truck.

rI_{131} himself participates in the loading and transporting of material from storage areas to loading ramp by using fork-lift tractors and handtrucks. He may also unload incoming material and transport it to

the storage area.

II. Task Set

The tasks identified for r_{131} are those given in the above table. Their timing standards are frequently explicitly set, e.g., "I want you to finish loading (or your part of unloading) this truck and get this fabric here to the ramp by lunch time since I have a truck coming in right after lunch." "I would like you to get all the fabric for this job to the ramp by quitting time so that the swing-shift crew can start loading the truck when it gets here. You can use both loaders for this if you need them."

The quality standards for $S^1_{131},\ldots,S^4_{131}$ are based on intuitive understandings between rI_{131} and rI_{23}. They were found to be very general and rather difficult to ascertain. For S^1_{131}, S^2_{131} and S^3_{131}, these standards are in terms of the degree of neatness, how and within which areas the material shall be moved and placed so as to minimize interferences between operations, etc. For S^4_{131} and also S^2_{131}, these are in the general terms of utilizing space so as to get a whole shipment on the truck (train).

III. Role Type

r_{131} is multi-task since $I^{km}_{131} \cap I^{k'm'}_{131} \neq \emptyset$ for $(k,k') = (2,4)$, $(3,4)$, $(3,3)$, $(4,4)$ and for more than one (m,m') if $T_{131} = \frac{1}{2}$ year.

IV. TSD Set and LOW

The longest time required (for $T_{131} = \frac{1}{2}$ year) to load and also to unload a shipment, which was found to correspond closely to the targeted completion time, was three hours so that $T^1_{131max} = T^2_{131max} = 3$ hrs.

rI_{131} is told by rI_{23} at the beginning of the day shift which

shipments have to be made during the day or during some specified period of the day and when the trucks or trains are scheduled to arrive. He may also be told to get some shipment(s) ready for loading by the swing-shift crew. rI_{23} may make certain scheduling changes during the day; however, rI_{131} may still remain responsible for some S_{131}^{3m} and S_{131}^{4m} throughout the shift.

It then follows that $T_{131max}^{3} = T_{131max}^{4} = 1$ day. T_{131min}^{k} and $\overline{T}_{131}^{k}$ obtained for $k = 1,\ldots,4$ are given in the above table. Thus, $\hat{L}_{131} \triangleq \max_{(k)} \{T_{131max}^{k}\} = 1$ day.

1. Role Title: Loader/Unloader (Day Shift), $r_{13j}(j=2,3)$
2. Immediate Superior: Foreman (Warehouse & Shipping), rI_{23}
3. Role Type: Multi-task
4. $\hat{L}_{132} = \hat{L}_{133} = \frac{1}{2}$ day
5. Summary Table:

Task Set $\{S^k_{13j}\}$	T^{km}_{13j}			Task Type: Continuous (c) Intermittent (i)
	T^k_{13jmin}	$\bar{T}^k_{13j}$	T^k_{13jmax}	
S^1_{13j} = unloads incoming material	10 min.	2 hrs.	3 hrs.	c
S^2_{13j} = loads outgoing material	10 min.	1 hr.	3 hrs.	c
S^3_{13j} = transports material	10 min.	2 hrs.	4 hrs.	c
S^4_{13j} = performs housekeeping	10 min.	$\frac{1}{2}$ hr.	4 hrs.	i, c

I. Role Content

The two loader/unloaders $rI_{13j}(j=2,3)$ perform loading, unloading and transporting of material just as the shipper rI_{131}. They also do some housekeeping, i.e., cleaning up the warehouse and shipping area, etc.

II. Task Set

The various tasks of r_{13j} are listed in the above table. The timing and quality standards for S^1_{13j} and S^2_{13j} and the quality standards for S^3_{13j} are generally comparable to those of the $S^k_{131}(k=1,2,3)$. However, the timing standards for S^3_{13j} are frequently not the same as for S^3_{131}. This is due to the fact that rI_{131}, who may have been given

"an all-day S^3_{131}", may assign some of this work to the rI_{13j} with shorter duration than one day (see also below). The timing standards for S^4_{13j} are set implicitly as frequently as they are set explicitly whereas the quality standards for S^4_{13j} are implicitly set in terms of the degree of neatness.

III. Role Type

r_{13j} is multi-task since $I^{km}_{13j} \cap I^{k'm'}_{13j} \neq \emptyset$ for $k = k' = 4$ and for more than one (m,m') if $T_{13j} = \frac{1}{2}$ year.

IV. TSD Set and LOW

As for rI_{131}, it was found that $T^1_{13jmax} = T^2_{13jmax} = 3$ hrs. S^3_{13j} is generally allocated to rI_{13j} by rI_{131} when one loading job has been completed and another shipment is scheduled to be made later during the day or during the swing shift. Once under way, S^3_{13j} may be interrupted since rI_{13j} may, for example, be required to unload a truck. The foreman may make this task reassignment himself or "I may check with my shipper on how the loaders are doing; if the one transporting rolls of fabric is keeping to the schedule, etc., then I may tell the shipper to pick this man to do the unloading. Before I have to make this kind of job changeover, I would say that I generally check, perhaps through the shipper, where the loaders are at in what they are doing."

Similar information was obtained regarding S^4_{13j}, which is also frequently allocated if there are no S^1_{13j}, S^2_{13j} or S^3_{13j} to attend to. It was found that $T^3_{13jmax} = T^4_{13jmax} = 4$ hrs. T^k_{13jmin} and $\bar{T}^k_{13j}$ obtained for $k = 1,\ldots,4$ are given in the above table. Thus, $\hat{L}_{13j} \triangleq \max_{(k)} \{S^k_{13jmax}\} = \frac{1}{2}$ day for $j = 2,3$.

1. Role Title: Loader/Unloader (Swing Shift), $r_{13j}(j=4,5)$
2. Immediate Superior: Foreman (Warehouse & Shipping), rI_{23}
3. Role Type: Multi-task
4. $\hat{L}_{134} = \hat{L}_{135} = 1$ day
5. Summary Table:

Task Set $\{S^k_{13j}\}$	T^k_{13jmax}	Task Type: Continuous (c) Intermittent (i)
S^1_{13j} = unloads incoming material	2 hrs.	i, c
S^2_{13j} = loads outgoing material	3 hrs.	i, c
S^3_{13j} = transports material	1 day	i
S^4_{13j} = performs housekeeping	1 day	i

I. Role Content

The two loader/unloaders $rI_{13j}(j=4,5)$ on the swing shift perform the same type of work as the $rI_{13j}(j=2,3)$ on the day shift.

II. Task Set

The tasks of r_{13j}, which are listed in the above table, have implicitly set quality standards that are similar to those for the $S^k_{132}(k=1,...4)$. Their timing standards are frequently explicitly set, e.g., "I want you first to get this material ready since there is a truck coming in a couple of hours. When you have loaded this truck, which should take you about an hour, why don't you get this rustake fence over here so we can ship it in the morning. Also clean up this mess here tonight".

III. Role Type

r_{13j} is multi-task since $I^{km}_{13j} \cap I^{k'm'}_{13j} = \emptyset$ for $(k,k') = (1,3)$, $(2,3),\ldots,(3,4),\ldots$, and for more than one (m,m') if $T_{13j} = \frac{1}{2}$ year.

IV. TSD Set and LOW

During the interval T_{13j} of length $\frac{1}{2}$ year, S^3_{13j} and S^4_{13j} were frequently allocated at the beginning of the swing shift and targeted for completion by the end of the shift. It was left up to rI_{13j} to decide when to actually start working on these tasks and how to distribute his time between them. At the beginning of the day shift, rI_{23} reviews his performance to see if he has completed S^3_{13j} and S^4_{13j}, etc. prior to planning the work for the day-shift crew. Thus, $T^3_{13jmax} = T^4_{13jmax} = 1$ day.

S^1_{13j} and S^2_{13j} obviously have allocation points corresponding to the arrival times of the trucks (trains). When considering their targeted completion times, which clearly do not coincide with any review instants, it was found that $T^3_{13jmax} = 2$ hrs. and $T^4_{13jmax} = 3$ hrs. Thus, $\hat{L}_{13j} \triangleq \max_{(k)} \{T^k_{13jmax}\} = 1$ day for $j=4,5$.

1. Role Title: Storeroomkeeper, r_{136}
2. Immediate Superior: Foreman (Warehouse & Shipping), rI_{23}
3. Role Type: Multi-task
4. $\hat{L}_{136}$ = 2 days
5. Summary Table:

Task Set $\{S^k_{136}\}$	T^{km}_{136}			Task Type: Continuous (c) Intermittent (i)
	T^k_{136min}	$\bar{T}^k_{136}$	T^k_{136max}	
S^1_{136} = unloads incoming material	10 min.	2 hrs.	4 hrs.	i, c
S^2_{136} = assembles material for shipping	10 min.	4 hrs.	1 day	i, c
S^3_{136} = takes parts and material inventory	2 days	2 days	2 days	i

I. Role Content

The storeroomkeeper rI_{136} unloads incoming material placing it in appropriate areas and shelves and also checks (together with the purchasing agent and traffic clerk) if this material agrees with that listed in the purchase requisition.

He also assembles material (small hardware) in sacks for shipment according to the bill of materials. Each sack is tagged with the customer's name and address, loaded onto a buggy and pushed to the loading ramp.

Once a month he takes the inventory of all parts and material. This information is recorded on the inventory form on which he also marks off those items whose inventory levels are low compared with the given reference levels.

II. Task Set

The tasks of r_{136} are listed in the above table. The timing standards for S^1_{136} are more frequently left unstated than explicitly stated whereas those for S^2_{136} and S^3_{136} are always explicitly set. "When a truck comes in with a load, he usually just starts to unload it without me always having to tell him and we both have a pretty good idea of how long it should take. I may tell him first thing in the morning that such and such jobs need to be assembled by such and such times since, for example, we are getting in a truck just before quitting time." "Two days each month for taking the inventory, including various interruptions, has become a standard by now."

The quality standards for S^1_{136}, S^2_{136} and S^3_{136} are all implicitly set. Those for S^1_{136} and S^2_{136} are in terms of how and where the material shall be moved and placed so as to minimize interferences between operations and to make it easy to pick the material up again, the tagging has to be sufficiently identifiable, etc. For S^3_{136}, it is required that the volume counts be within certain general limits of accuracy.

III. Role Type

r_{136} is multi-task since $I^{km}_{136} \cap I^{k'm'}_{136} \neq \emptyset$ for $(k,k') = (1,2)$, $(1,3)$, $(2,3)$, $(2,2)$, $(1,1)$ and for more than one (m,m') if $T_{136} = \frac{1}{2}$ year.

IV. TSD Set and LOW

Since rI_{136} checks the incoming material against purchase requisitions and may have to sort out some of the material before it is stored, it was found that $T^1_{136max} = 4$ hrs. rather than the 3 hrs. for S^1_{131} and S^1_{132}.

He may be told by rI_{23} at the beginning of the shift what has to be assembled by the end of the shift (he may also be given some additional assembling during the day) so that $T^2_{136max} = 1$ day. It also follows from above (see II, rI_{136} was found to remain responsible for S^3_{136} during periods of interruptions) that $T^3_{136max} = 2$ days. T^k_{136min} and $\overline{T}^k_{136}$ obtained for k = 1,2,3 are given in the above table. Thus, $\hat{L}_{136} \triangleq \max_{(k)} \{T^k_{136max}\} = 2$ days.

1. Role Title: Shipping Clerk, r_{137}
2. Immediate Superior: Foreman (Warehouse & Shipping), rI_{23}
3. Role Type: Multi-task
4. $\hat{L}_{137}$ = 1 day
5. Summary Table:

Task Set $\{S^k_{137}\}$	T^{km}_{137}			Task Type: Continuous (c) Intermittent (i)
	T^k_{137min}	$\bar{T}^k_{137}$	T^k_{137max}	
S^1_{137} = unloads incoming material	10 min.	2 hrs.	3 hrs.	i, c
S^2_{137} = assembles material for shipping	10 min.	4 hrs.	1 day	i, c
S^3_{137} = loads outgoing material	10 min.	1 hr.	3 hrs.	i, c
S^4_{137} = performs housekeeping	10 min.	$\frac{1}{2}$ hr.	4 hrs.	c

I. Role Content

The shipping clerk rI_{137} unloads and loads material and does some housekeeping as do the loader/unloaders $rI_{13i}(i=2,3)$. Like the storeroomkeeper rI_{136}, he also assembles and tags material for shipping.

II. Task Set

The various tasks of r_{137} are listed in the above table. Their timing and quality standards are similarly set to those of the $S^k_{132}(k=1,2,4)$ and the $S^k_{136}(k=1,2)$.

III. Role Type

r_{137} is multi-task since $I^{km}_{137} \cap I^{k'm'}_{137} \neq \emptyset$ for $(k,k') = (1,2)$,

(2,3), (1,1), (2,2) and for more than one (m,m') if $T_{137} = \frac{1}{2}$ year.

IV. TSD Set and LOW

As for S^k_{13j}(j=2,3; k=1,2,4) and S^2_{136}, it was found that $T^1_{137max} = T^3_{137max}$ = 3 hrs., T^2_{137max} = 1 day and T^4_{137max} = 4 hrs. T^k_{137min} and $\bar{T}^k_{137}$ obtained for k = 1,...,4 are given in the above table. Thus, $\hat{L}_{137} \triangleq \max_{(k)} \{T^k_{137max}\}$ = 1 day.

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MAINTENANCE AND STAFF

Process Description

Maintenance

The plant's maintenance department, in addition to performing some production type work such as machining sprockets for conveyor belts, making dies, etc., handles all* the maintenance work in the plant and equipment betterments. Both preventive and emergency maintenance is performed by this department's four mechanics (one of whom works on the swing shift). There is some specialization; however, any one of the mechanics is capable of performing the whole range of work.

Whenever there is any equipment breakdown in a department, the formal procedure is for the department's foreman to fill out a maintenance card identifying the equipment and indicating the type of breakdown. This card is given to the maintenance supervisor who then

1) checks the breakdown in order to determine its extent and the expected repair time,
2) determines the urgency for repair as compared to the work his crew is presently doing, and
3) schedules the repair job and assigns it to his mechanic(s).

If the supervisor is not present at the time of equipment breakdown, the foreman may himself request a mechanic to repair it. In some instances such as a relatively minor breakdown or if the foreman is not present, the equipment operator may go directly to the maintenance mechanic or to the supervisor.

Preventive maintenance is performed periodically on various pieces

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* Some minor repairs may also be done by members of the production departments' crews such as the mechanic rI111 in the weaving department.

of equipment (see role-content analysis of r_{141}) whereas equipment betterments or updatings are frequently long-term projects attended to intermittently.

The maintenance shop is equipped with lathes, milling machines, drill presses, grinders, welding machines, shavers and various hand-tools. Any one of the mechanics is an experienced operator of all this equipment.

Staff

The staff department is composed of a layout draftsman, janitor, departmental clerk and a purchasing agent and traffic clerk. The functions of the first two of these roles, which were analyzed in this study, are described below.

1. Role Title: Supervisor (Maintenance & Staff), r_{24}
2. Immediate Superior: Superintendent, rI_3
3. Role Type: Multi-task
4. $\hat{L}_{24}$ = 4 months
5. Summary Table:

Task Set $\{S_{24}^k\}$	T_{24}^{km} $T_{24min}^k = \overline{T}_{24}^k = T_{24max}^k$	Task Type: Continuous (c) Intermittent (i)
S_{24}^1 = analyzes and reports on safety (housekeeping and safety devices)	1 week	i
S_{24}^2 = analyzes and reports on safety (tools)	1 month	i
S_{24}^3 = makes safety contacts with subordinates	1 week	i
S_{24}^4 = analyzes and reports on safe job procedures	1 month	i
S_{24}^5 = prepares cost forecasts (tools, supplies, etc.)	2 weeks	i
S_{24}^6 = undertakes special projects	4 months*	i
S_{24}^7 = supervises his subordinate systems	1 month	i
S_{24}^8 = reviews all safety reports	2 days	i

* T_{24min}^6 = 1 day, $\overline{T}_{24}^6$ = 1 month, T_{24max}^6 = 4 months

I. Role Content

This supervisor rI_{24} performs comparable type of work to that of

the foreman rI_{21}. The main difference in general role content between the two is that rI_{24} a) was not responsible for training any new subordinates during the interval T_{24} of length 2 years, b) reviews all safety programs in which the foremen participate and report on in addition to himself directly participating in these programs and c) is more involved in various types of special projects than rI_{21} is.

rI_{24}'s major responsibility is the planning, monitoring and control of the operations performed by his subsystem (effector) consisting of the plant's maintenance and staff facilities and a crew of eight role incumbents. The planning function involves the determination of specific work requirements and schedules for individual preventive and emergency manitenance jobs as well as for production and staff assignments (see also the process descriptions and role-content analyses of the $r_{14j}(j=1,\ldots,6)$). The standard performance requirements for the individual operations allocated to each of the $rI_{14j}(j=1,\ldots,6)$ are outputs of this planning system. It is then the purpose of rI_{24}'s control and feedback monitoring process to ensure that these desired performance requirements are being realized.

II. Task Set

The various tasks of r_{24} are listed in the above table. The timing and quality standards for $S^1_{24},\ldots,S^5_{24}$ are similarly set to those for $S^1_{21},\ldots,S^5_{21}$. For S^6_{24}, the comments given for S^6_{21} apply. rI_{24}, who spends considerably more of his time on S^6_{24} than does rI_{21} on S^6_{21} and rI_{23} on S^6_{23}, is involved in projects ranging from the development of a simple system for storing personnel records to complex projects such as replacing the galvanizing kettle and building a new pickle line.

The timing standards for S_{24}^{8} are explicitly set; rI_{24} is given about two days during which to perform S_{24}^{8} before the reports are to be given to rI_{3}.

For S_{24}^{7}, similar comments as those given for S_{21}^{7} and S_{23}^{7} apply. This general task encompasses in particular the planning and closed-loop control of the individual maintenance and minor production operations performed by the rI_{14j}. These individual planning and control functions S_{24}^{7m} are generated by "general responsibilities" rather than by direct task allocations of rI_{3}. Only for relatively "major" S_{24}^{7m} does there appear to be definite ascertainable targeted completion points implicitly or explicitly set by rI_{3}. Such major S_{24}^{7m} are typically maintenance jobs that require equipment shutdown during the repair interval and/or the incurrence of considerable cost. These types of disturbances and their eliminations such as the breakdown and repair of the galvanizing furnace are monitored by rI_{3} since they may require rI_{3} to alter his own control strategy (adapt his control behavior) and perhaps ultimately his operating plans. In general, however, it appears that as for S_{21}^{7m} and S_{23}^{7m}, rI_{3} is primarily concerned with the aggregate closed-loop control of the accumulated resource deployment variable of the systems S_{24}^{7m}. The requisite feedback information is provided by the monthly cost statement from the accounting department.

III. Role Type

r_{24} is multi-task since $I_{24}^{km} \cap I_{24}^{k'm'} \neq \emptyset$ for $(k,k') = (1,2), (2,3), (1,4), \ldots, (1,6), (7,8), \ldots$, and for more than one (m,m') if T_{24}=2 years.

IV. TSD Set and LOW

It follows from the preceding analysis that for all m, $T_{24}^{1m} = T_{24}^{3m} =$

= 1 week, $T_{24}^{2m} = T_{24}^{4m}$ = 1 month, T_{24}^{5m} = 2 weeks and T_{24}^{8m} = 2 days. For S_{24}^{6}, it was found that T_{24min}^{6} = 1 day, $\overline{T}_{24}^{6}$ = 1 month and T_{24max}^{6} = = 4 months. If the resource deployment review interval of #II above is considered to determine the TSD of the composite task S_{24}^{7}, then T_{24}^{7} = = 1 month. Thus, $\hat{L}_{24} \triangleq \max_{(k)} \{T_{24max}^{k}\}$ = 4 months.

1. Role Title: Maintenance Mechanic (Day Shift), $r_{14j}(j=1,2,3)$
2. Immediate Superior: Supervisor (Maintenance & Staff), rI_{24}
3. Role Type: Multi-task
4. $\hat{L}_{14j}$ = 1 day for j = 1,2,3.
5. Summary Table:

Task Set $\{S^k_{14j}\}$	T^{km}_{14j}			Task Type: Continuous (c) Intermittent (i)
	T^k_{14jmin}	$\bar{T}^k_{14j}$	T^k_{14jmax}	
S^1_{14j} = performs emergency maintenance	10 min.	1 hr.	1 day	c
S^2_{14j} = performs preventive maintenance	15 min.	1 hr.	1 day	c
S^3_{14j} = performs production work	15 min.	4 hrs.	1 day	i, c
S^4_{14j} = updates existing equipment	15 min.	6 hrs.	1 day	i, c

I. Role Content

The three mechanics $rI_{14j}(j=1,2,3)$ perform essentially the same type of work except for some areas of specialization. Their "major responsibility is breakdowns", i.e., repairing equipment in any of the departments that need immediate repairs. Much of their time is spent on regularly recurring preventive maintenance work of a wide variety such as replacing air-compressor filters, checking the heating-cooling system and checking the points on the hoists. There is some degree of specialization in this area of work; one mechanic checks all fork-lift tractors, another one checks all electrical controls on the galvanizer, and the third is responsible for checking some of the crucial mechanical parts

of the pickling and galvanizing lines. These activities are performed each morning before the equipment is being used; others are performed weekly, monthly, etc.

They also perform some production work such as machining conveyor belt sprockets from rough castings, making steel rods, tools and dies. Even though they all three may do any of this work, they do specialize so that, for instance, the most highly skilled mechanic on sprockets may produce a rush order of sprockets without interruptions (unless there are too many equipment breakdowns for the other two mechanics to handle).

They also modernize existing equipment in the shops, making and installing new equipment components such as counters for the weaving machines, special forks for the tractors and a new pickle line.

II. Task Set

The tasks identified for r_{14j} are listed in the above table. Quality standards are generally explicitly set in terms of tolerances such as $x \pm 0.001$ for S^3_{14j} whereas for S^1_{14j}, S^2_{14j}, and S^4_{14j}, these standards are generally set by intuitive understandings between rI_{14j} and rI_{24}. The timing standards for the $S^k_{14j}(j=1,\ldots,4)$ are both explicitly and implicitly set. "When any job comes up, I generally get together with these people, we discuss how the job should be done, we come up with some kind of estimate of how long this job ought to take, etc. When they start working on this job, they definitely have, in your terminology, both quality and timing standards set for the job and they know that the final job has to meet these standards. Yes, I would definitely hear about it one way or another if their work didn't hold up to these standards."

III. Role Type

r_{14j} is multi-task since $I^{km}_{14j} \cap I^{k'm'}_{14j} \neq \emptyset$ for $(k,k') = (3,4)$, $(3,3)$, $(4,4)$ and for more than one (m,m') if $T_{14j} = \frac{1}{2}$ year.

IV. TSD Set and LOW

The t^{km}_{t14j} were found to coincide in general with actual completion instants for $k = 1,2$ and for all m. For S^3_{14j} and S^4_{14j}, however, the initial t^{km}_{t14j} were found to be frequently changed during the corresponding I^{km}_{t14j} periods because of priori interruptions caused by allocations of S^1_{14j} and S^2_{14j}. Whenever this happens, "I check with my men where they are in their work and take the one off that is most convenient and let him handle the breakdown. I would then also have noticed it if he were behind schedule (i.e., regarding S^3_{14j} and S^4_{14j})."

Some projects associated with S^3_{14j} and S^4_{14j} may last for several weeks or months before they are completed; however, the above types of interruptions limit the periods during which a mechanic is continuously responsible for S^3_{14j} and S^4_{14j} to no more than a few days. Furthermore, the mechanic rI_{144} on the swing shift is always told to do some work on projects associated with S^3_{14j} and S^4_{14j} as well as with S^1_{14j} and S^2_{14j} that the rI_{14j} did not complete. "I will see the swing-shift mechanic just before I quit for the day. I will then review the day's work by the other three and on the basis of this I will tell the swing-shift man to try and do approximately so and so much on each job that the day-shift mechanics did not finish. The next morning I will then check where he left off and assign more of this work to my day-shift men."

For $T_{14j} = \frac{1}{2}$ year and because of the above comments, it was found for all the mechanics that $T^k_{14j} = 1$ day for $k = 1,2,3,4$. T^k_{14jmin} and

$\overline{T}^{k}_{14j}$ obtained for all k are given in the above table. Thus, $\hat{L}_{14j} \triangleq$

$\triangleq \max_{(k)} \{S^{k}_{14j\max}\} = 1$ day for $j = 1,2,3$.

1. Role Title: Maintenance Mechanic (Swing Shift), r_{144}
2. Immediate Superior: Supervisor (Maintenance & Staff), rI_{24}
3. Role Type: Multi-task
4. $\hat{L}_{144}$ = 2 days
5. Summary Table:

Task Set $\{S^k_{144}\}$	T^k_{144max}	Task Type: Continuous (c) Intermittent (i)
S^1_{144} = performs emergency maintenance	1 day	c
S^2_{144} = performs preventive maintenance	1 day	i, c
S^3_{144} = performs production work	1 day	i
S^4_{144} = updates existing equipment	1 day	i
S^5_{144} = oversees plant security	2 days	i

I. Role Content

This maintenance mechanic rI_{144} performs identical type of work to the $rI_{14j}(j=1,2,3)$ on the day shift whose job description is given above except for his additional responsibility of overseeing the overall security of the plant. This involves checking that the gates are closed at all times, that no unauthorized personnel enters the plant and that any injuries are given proper medical attention.

II. Task Set

The tasks of r_{144} are listed in the above table. The quality and timing standards for $S^1_{144},\ldots,S^4_{144}$ are similarly set to those of the $S^k_{14j}(k=1,\ldots,4)$ for $j = 1,2,3$. These standards for S^5_{144} are indicated below.

III. Role Type

r_{144} is multi-task since $I^{km}_{144} \cap I^{k'm'}_{144} \neq \emptyset$ for $(k,k') = (2,3)$, $(2,4),\ldots,(5,4),\ldots$, and for more than one (m,m') if $T_{144} = \frac{1}{2}$ year.

IV. TSD Set and LOW

The S^2_{144}, S^3_{144}, S^4_{144} are allocated at the beginning of the shift through such supervisory instruction as "I would like you to do about so and so much on each of these tasks. I definitely want you to complete these (S^2_{144}, S^3_{144}) jobs if there are not too many breakdowns (i.e., S^1_{144} projects), then do as much as you can on this (S^4_{144}) job". The order in which these tasks are attended to is generally left up to rI_{144} to decide. The t^{1m}_{a144} correspond to the instants at which equipment breakdowns occur; S^1_{144} is generated by a "general responsibility" in Jaques' terminology, i.e., whenever a breakdown is reported, rI_{144} has been instructed to take care of this immediately.

"The first thing I do when I come to work is to check what the mechanic did during the swing shift. I check which breakdowns he had worked on...he records information like this...and I check if the rest of his work was done as we had kind of agreed upon. On the basis of this, I then assign my day-shift men to work on jobs that the swing-shift mechanic did not complete and so on. Yes, he may work a whole shift on some major breakdown."

S^5_{144} has to be performed such that no unauthorized person enters the plant, personnel injuries are properly taken care of, etc. "If he has been rather lax about this during a shift, I may notice this in the morning. I would definitely be aware of this at the end of the next day when I meet with this mechanic or when some foreman may be informed about it through his swing-shift crew." It does appear that gross

errors would be discovered by rI_{24} no later than at the beginning of the day shift whereas continuous and marginally substandard performance would be detected at the end of the day shift so that $T_{144}^{5m} = 2$ days for all m.

For $T_{144} = \frac{1}{2}$ year, it was found that $T_{144max}^{1} = 1$ day and from the preceding analysis it follows that $T_{144max}^{k} = 1$ day for k = 2,3,4 where $T_{144}^{km} = 1$ day for k = 2,3,4 and for most m. Thus, $\hat{L}_{144} \triangleq$ $\triangleq \max_{(k)} \left\{ T_{144max}^{k} \right\} = 2$ days.

1. Role Title: Janitor, r_{145}
2. Immediate Superior: Supervisor (Maintenance & Staff), rI_{24}
3. Role Type: Multi-task
4. $\hat{L}_{145} = 7\frac{1}{2}$ hrs.
5. Summary Table:

Task Set $\{S^k_{145}\}$	T^{km}_{145}			Task Type: Continuous (c) Intermittent (i)
	T^k_{145min}	$\bar{T}^k_{145}$	T^k_{145max}	
S^1_{145} = empties garbage cans & cleans shop aisles	$\frac{1}{2}$ hr.	$\frac{1}{2}$ hr.	$\frac{1}{2}$ hr.	c
S^2_{145} = cleans offices, toilets,etc.	$7\frac{1}{2}$ hrs.	$7\frac{1}{2}$ hrs.	$7\frac{1}{2}$ hrs.	i
S^3_{145} = performs odd jobs (painting, concrete work, etc.)	10 min.	6 hrs.	$7\frac{1}{2}$ hrs.	i

I. Role Content

The janitor rI_{145}, who works during the swing shift, empties all the garbage cans and cleans the shop aisles during the first $\frac{1}{2}$ hr. or so of his shift. During the rest of the shift, he cleans the office area and toilets and maintains the supply of paper and soap, etc. He is also frequently assigned various odd jobs such as painting, concrete work and window cleaning.

II. Task Set

The tasks identified for r_{145} are listed in the above table. The timing standards are explicitly set; S^2_{145} has to be completed by the end of the swing shift and a S^3_{145} project lasting for more than one

shift is broken down into sub-projects, each targeted for completion by the end of a shift. "I always like to inform this man about the whole scope of a project, However, I try as explicitly as possible to tell him what I would like him to do on a project during the shift." For S^1_{145}, "this is the first thing he does so that by the time I quit for the day I would have discovered it or received feedback about it if he had not done this work satisfactorily (w.r.t. to both quality and timing)".

III. Role Type

r_{145} is multi-task since $I^{km}_{145} \cap I^{k'm'}_{145} \neq \emptyset$ for $(k,k') = (2,3)$, $(3,3)$ and for more than one (m,m') if $T_{145} = \frac{1}{2}$ year.

IV. TSD Set and LOW

From the above analysis it follows that $T^{1m}_{145} = \frac{1}{2}$ hr. and $T^{2m}_{145} = 7\frac{1}{2}$ hrs. for all m. Although most S^3_{145} projects are scheduled for completion by the end of a shift, some projects may be allocated during a shift such that $t^{3m}_{a145} = t^{3(m-1)}_{145}$ for at least one m (where $t^{3(m-1)}_{145}$ obviously does not coincide with a timing review instant). It was thus found that $T^3_{145min} = 10$ min., $\bar{T}^3_{145} = 6$ hrs. and $T^3_{145max} = 7\frac{1}{2}$ hrs. Thus, $\hat{L}_{145} \triangleq \max_{(k)} \{T^k_{145max}\} = 7\frac{1}{2}$ hrs.

1. Role Title: Layout Draftsman, r_{146}
2. Immediate Superior: Supervisor (Maintenance & Staff), rI_{24} and Superintendent, rI_3
3. Role Type: Multi-task
4. $\hat{L}_{146}$ = 2 weeks
5. Summary Table:

Task Set $\{S^k_{146}\}$	T^{km}_{146}			Task Type: Continuous (c) Intermittent (i)
	T^k_{146min}	$\bar{T}^k_{146}$	T^k_{146max}	
S^1_{146} = tests galvanized fabric	—	—	—	—
S^2_{146} = specifies and does drafting	10 min.	1 day	2 weeks	i
S^3_{146} = prepares "chain-link and zinc requirements for month x" form	1 day	1 day	1 day	i
S^4_{146} = fills out interworks orders	10 min.	$\frac{1}{2}$ day	2 weeks	i, c
S^5_{146} = takes minutes and checks safety compliances	1 week	1 week	1 week	i

I. Role Content

The layout draftsman rI_{146} performs all the testing of galvanized fabric produced in the plant. A one foot long wire specimen from every 25 or 50 rolls of fabric is tested for tensile strength and coating weight to ensure that the customer product specifications are met. The specifications for a job as given in the sales order are interpreted by rI_{146} and translated into a production order consisting of bills of

material and sometimes layout drawings, one copy of which goes to the foreman rI_{21} and another one to the foreman rI_{23}.

During the first day of each month, rI_{146} has to compile information regarding the quantity of zinc and different gage wire that need to be ordered for the next month. rI_{21} provides him with figures for the projected requirements for wire and zinc based on expected machine hours for that month, rate of wire and zinc consumption and the expected volume ratios of different wire gages. These projected figures are then compared with the present inventory size (obtained from the accounting department) and with previous outstanding orders to give estimates of the wire and zinc quantity that should be ordered for the next month. All this information is presented on a "chainlink and zinc requirements for month x" form which is reviewed by the plant's superintendent. If it is decided that zinc and wire have to be ordered, rI_{146} fills out a purchase requisition ("interworks order") which is teletyped to the company's production planning office which then arranges for the order to be sent.

rI_{146} fills out all interworks orders, i.e., purchase requisitions for parts and material produced by the various plants of the steel company. He translates a standard purchase requisition, filled out by someone in the plant and signed by the superintendent, into an interworks order. This involves adding proper specifications, etc.

He also acts as the secretary of a safety committee meeting once a month. His job entails taking minutes from these meetings and also checking that various safety recommendations are complied with.

II. $\{S^k_{146}\}$, Role Type, $\{T^{km}_{146}\}$ and $\hat{L}_{146}$

The tasks identified for r_{146} are those listed in the above table. The role is clearly multi-task since $I^{km}_{146} \cap I^{k'm'}_{146} \neq \emptyset$ for $(k,k') = (1,2)$, $(2,3)$, $(3,4)$,... and for more than one (m,m') if $T_{146} = 1$ year.

The T^k_{146min}, $\bar{T}^k_{146}$ and T^k_{146max} obtained are given in the above table for $k = 2,...,5$; for $k = 1$, it was only established that $T^1_{146max} \ll \ll \max_{(k)} \{T^k_{146max}\}$. From these data it follows that $\hat{L}_{146} \triangleq \max_{(k)} \{T^k_{146max}\} = 2$ weeks.

APPENDIX B

Naval Air Rework Facility (Firm B)

COMMENTS TO APPENDIX B

In the case of firm B, the TSD analyses made were much less extensive than those for firm A. Only some general comments directly related to the LOW estimates will be given subsequently. For the shopfloor roles and first-line supervisors, these comments are presented specifically for roles belonging to branch 433 (P3 A/C Rework) but also apply to foremen in branch 422 (Electrical & Missiles) and to some extent to the shopfloor roles of # 422.

All the roles analyzed were found to be multi-task so that we needed only consider targeted completion points for the LOW estimation.

LEVEL-1 ROLES

The work performed by the shops $2335\ell(\ell=1,\ldots,4)$ is done according to a standard breakdown by distinct areas for each aircraft. Similarly, each of the shops $2223\ell(\ell=1,\ldots,4)$ is devided into areas of specialization. One or more roles are associated with each one of these areas. Each role requires its incumbent to perform specialized functions, although the requisite skills are transferable to some extent. Thus, one individual who generally operates in one particular area is capable of performing some or all of the tasks in other areas within the same shop or in some other shop of the section. Depending on differentials in workload between areas, it is quite common that an individual occupies several roles during a given time period. This applies to persons belonging to any of the five job classifications common to each shop, i.e., Airframes Mechanic, A/C Electrician, Worker , Helper and Apprentice.

The work to be done in each area is specified by a set of "work cards". These cards also give standard times for component removal, installation and overhaul. Thus, when a role incumbent $rI_{1335\ell m}$ is assigned the work in an area, both he and his immediate supervisor $rI_{2335\ell}$ know the targeted completion times for the tasks to be performed. These time standards may in some instances be too tight or too loose so that $rI_{1335\ell m}$ and $rI_{2335\ell}$ may have some other standards in mind that determine the TSD's and the LOW estimates. It should also be noted that the swing-shift crew may be assigned to work in areas that are generally the domain of the day-shift personnel. However, any one of the persons on day shift may perform all the work (his part of the work) in an area. Based on such targeted completion times and the

finding that all roles analyzed are multi-task, the following LOW data were obtained:

$\{r_{13352m}\}$ — 1 hr. $\leq \hat{L}_{13352m} \leq$ 2 days, $\bar{\hat{L}}_{13352} \approx$ 1 day

i.e., the LOW estimates for these roles range from 1 hr. to 2 days, the algebraic mean of which is about 1 day. For an analysis interval of length $T_{13352m} = \frac{1}{2}$ year for all m, several of the 16 role incumbents occupy roles resulting in LOW estimates of 1 day; only one or two individuals attain LOW estimates of 2 days.

$\{r_{13351m}\}$ — 3 days $\leq \hat{L}_{13351m} \leq$ 5 days

Only two of the 21 role incumbents attain LOW estimates of 5 days.

$\{r_{13353m}\}$ — 1 hr. $\leq \hat{L}_{13353m} \leq$ 5 days, $\bar{\hat{L}}_{13353} \approx 2\frac{1}{2}$ days

At least two of the 24 role incumbents attain LOW estimates of 5 days.

$\{r_{13354m}\}$ — 1 hr. $\leq \hat{L}_{13354m} \leq$ 4 days, $\bar{\hat{L}}_{13354} \approx$ 3 days

At least two of the 13 role incumbents attain LOW estimates of 4 days.

For the roles $r_{1223\ell m}(\ell=1,\ldots,4;\ m=1,2,\ldots)$, the LOW range was estimated to be from 1 hour to 7 days (working days). Several of the role incumbents were found to attain LOW estimates ranging from 5 to 7 days.

LEVEL-2 ROLES

The task whose TSD determines the LOW estimate for all the first-supervisors $rI_{2335\ell}(\ell=1,..,4)$ (and also the $rI_{2223\ell}(\ell=1,..,4)$) was found to be that of training apprentices. A foreman $rI_{2335\ell}$ is frequently assigned an apprentice for a specific time interval during which $rI_{2335\ell}$ is partly responsible (see also analysis of level-3 roles below) for ensuring that an apprentice is exposed to the various operations of the shop and for monitoring his progress and reporting on it

in a general monthly progress report. At the end of the originally scheduled training period, $rI_{2335\ell}$ may be told by his superior rI_{3335} to keep the apprentice during an additional time interval because he either has not been progressing properly or he is needed by the shop due to a heavy workload.

The TSD for this task is thus not necessarily equal to the total time period for which $rI_{2335\ell}$ had the apprentice. It is clearly equal to the length of the longest of the above two intervals, i.e., the originally scheduled interval and the extension interval. It should also be added that the $r_{3335\ell}(\ell=1,..,4)$ are all multi-task. Then, for $T_{2335\ell} = 1$ year for all ℓ, the following LOW estimates were obtained:

$$\hat{L}_{2335\ell} = \begin{cases} 3 \text{ months for } \ell = 1 \\ 2 \text{ months for } \ell = 2 \\ 3 \text{ months for } \ell = 3 \\ 2 \text{ months for } \ell = 4 \end{cases}$$

The results obtained for the $rI_{2223\ell}(\ell=1,..,4)$ are those given in Fig. 12 above (the two left-hand side columns).

LEVEL-3 ROLES

The LOW estimate for rI_{3335} was found to be determined by the TSD for the task of coordinating the training of the aircraft electrician apprentices in the 433 branch. As part of his 4-year training program, an electrician apprentice spends 16 months in the 53 division, 14 months of which may be in # 433 and the remaining 2 months in # 434. During these 14 months, rI_{3335} is responsible for ensuring that an apprentice is exposed to the various rudiments of the trade. This entails the intermittent monitoring of the apprentice's progress (recei-

ving some of this feedback information through the $rI_{2335\ell}$). On the basis of this feedback information and standing progressive performance requirements, rI_{3335} determines the training schedule for the apprentice. Thus, $\hat{L}_{3335}$ = 14 months.

For rI_{3223}, however, difficulty was experienced when attempting to evaluate his LOW performed. This difficulty was partly attributable to the fact that (i) rI_{3223} had occupied the role r_{3223} for only a short time and (ii) definite targeted completion points were not easily ascertainable. The following observations led us to accept $\hat{L}_{3223} \approx 1$ year as a tentative estimate. Firstly, the task of training apprentices, which determined $\hat{L}_{3335}$, is partly the responsibility of rI_{3223} but has a TSD of only 6 months since rI_{3223} is given 6-month schedules for the aircraft electrician apprentices. Secondly, rI_{3223} is involved in various projects whose TSD may exceed 6 months such as shop layout changes, shop equipment changes, Z-D (zero-defects), modifications of manhour processing in the cost accounting system, etc. Some of these projects, particularly the last one, appeared to have TSD's of the order of 1 year although the targeted completion points were poorly defined.

LEVEL-4 ROLES

As is generally found to be the case for higher-level supervisors, the LOW estimates $\hat{L}_{433}$ and $\hat{L}_{422}$ are determined by tasks concerning special development projects. Both rI_{433} and rI_{422} are assigned a variety of such projects many of which are concerned with adapting their respective facilities to changes in aircraft and missile components and to handling new types of aircraft and missiles (only rI_{422} handles missiles).

Such adaptive changes may require new tools and equipment by the shops, new maintenance procedures, etc. and retraining of personnel. It is the responsibility of rI_{433} and rI_{422}, in cooperation with members of other departments (eg., Operations Analysis) as well as with the manufacturers, to determine the extent of such changes and then to assist in carrying them through.

On the basis of such projects and for $T_{433} = T_{422} \approx 6$ years, it was estimated that $\hat{L}_{433} = \hat{L}_{422} \approx 3$ years.