COMPUTER SIMULATION OF COMBINE HARVESTING AND HANDLING OF SUGAR CANE IN BARBADOS

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ABSTRACT

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OF SUGAR CANE IN BARBADOS

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The broad objective of this study was to improve the efficiency of combine harvesting of sugar cane in Barbados. The harvesting process was broken down into two subsystems: a field subsystem and a factory yard subsystem. Two computer simulation models, structured in GASP IV simulation language, were developed to model the operations involved in these systems. Model FIELDOP simulated the activities involved in the harvesting and loading of cane in the field, and in its transportation to the factory for processing. Model FACYARD simulated the weighing and unloading activities performed on cane transport units at the factory.

Following validation of the models, four different factory yard configurations and eight different field equipment combinations were simulated. Model parameters varied were the number of factory yard scales and the numbers of field tractors and cane transport wagons assigned to a harvester.

Output from the models included utilization factors for the various component machines, daily cane delivery from the field system, and daily amounts of cane handled by the factory yard system. This output was fed into a cost program which calculated unit harvesting costs and total annual cane delivery for the equipment combinations simulated.

Results indicated that a second scale at the factory can reduce the factory residence time of transport units by 88 percent, increase combine

harvester utilization efficiency by 50-60 percent, increase daily cane receipts at the factory by more than 30 percent, and eliminate milling lost time due to lack of cane. Harvesting systems using two field tractors, rather than one, were also shown to be capable of consistently delivering 15-25 percent more cane per day.

The economic analysis demonstrated that harvesting cost per tonne can be significantly reduced by either adding a second field tractor, increasing the number of cane wagons assigned to a harvester, installing a second weigh scale at the factory, or a combination of these.

A sensitivity analysis revealed that, as a single measure, adding a second scale to the factory would be two to three times more effective in reducing costs then would either of the other measures.

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Major Professor

Approved ______________________________
Department Chairman

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CHAPTER 1

INTRODUCTION

1.1. Background

Barbados, located 59° 37' east longitude and 13° 4' north latitude, is the most easterly of the archipelago of islands in the Caribbean Sea. It is a small island of 430 square kilometres, 43,000 hectares of land and a population density of approximately 580 persons per square kilometre. (Figure 1.1).

Colonized by the British for over 300 years, the island has an economic history which is divisible into three main phases. The first phase, 1627-1650, was characterized by a peasant economy in which an inexcessive number of settlers pursued a relatively self-sufficient and diversified economy based on the production of tobacco, cotton and indigo.

The second phase, 1651-1950, saw the island transformed into a rigid and 'lop-sided' export oriented plantation economy dependent almost exclusively on sugar cane production. During this period scarcely any effort was made to exploit what limited opportunities existed for diversification, even within the dominant agricultural sector. The third and current phase, which began in the 1950s, has so far been characterized by the political decline of the white planter class and a concomitant increase in the number of somewhat more

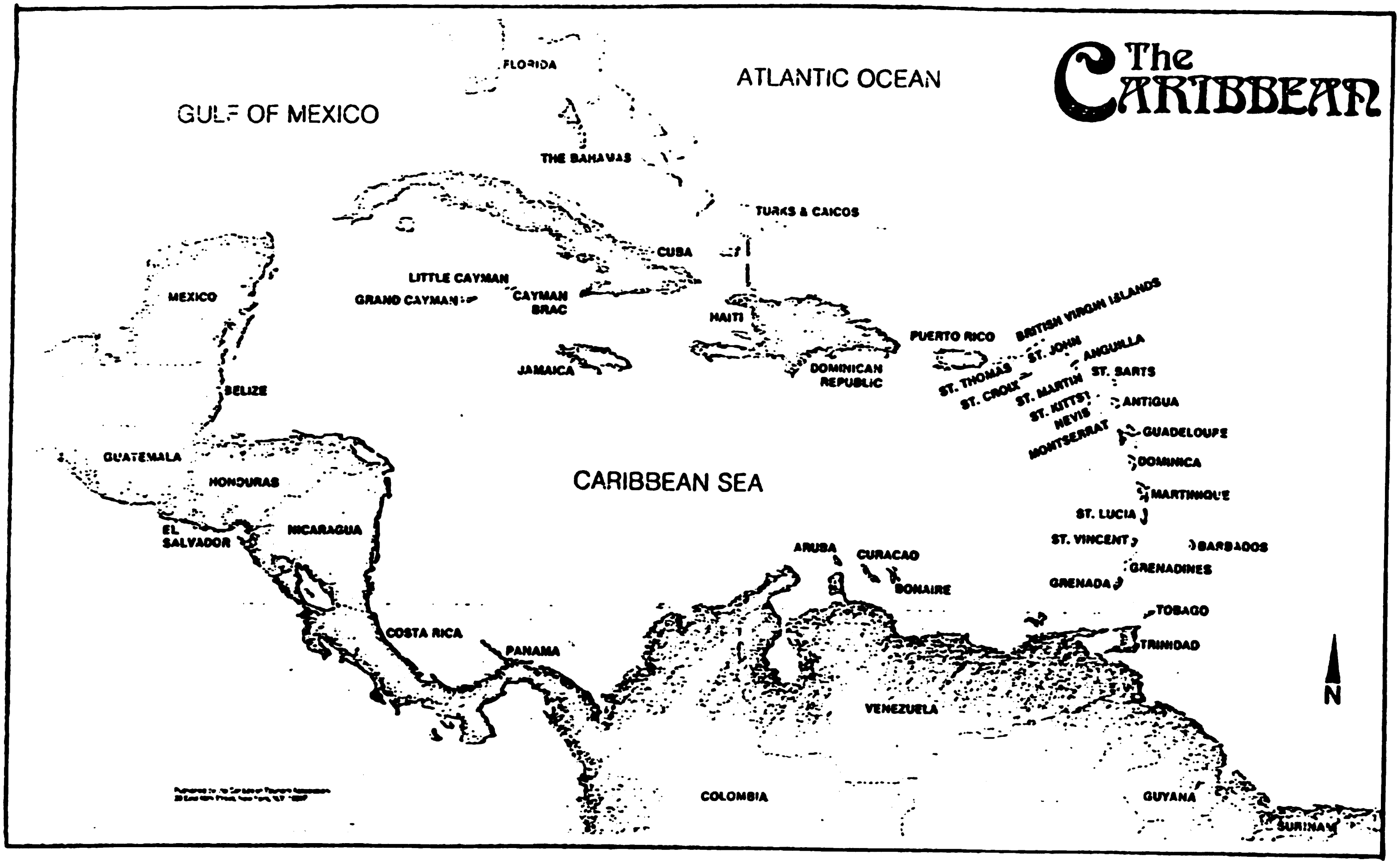


Figure 1.1 The geographic location of Barbados.

democratic black rulers. In pursuit of a more self-sustaining economy, attempts have been made to promote optimum use of the country's limited resources and to diversify its production structure. Measures taken include human resource development, growth and development of a viable fishing industry, development of vibrant tourism and manufacturing sectors, diversification within the agricultural sector and, more recently, on and off-shore oil and natural gas exploration.

Agricultural diversification has involved the development of livestock production, the establishment of non-plantation cash crops (mainly food crops and Sea-Island cotton) and modernization of the dominant sugar industry. Such modernization was initially restricted to mechanization of the land preparation and cultural practices involved in the sugar cane production process. Due to steadily declining harvest labour availability and escalating harvest labour costs, however, recent modernization efforts have concentrated on mechanization of the harvesting and handling activities and it is on this very area that this study is focussed.

1.2. Objective of the Study

This study is concerned with mechanical harvesting and handling of sugar cane in general and, in particular, with the chopper combine harvesting systems currently in use in Barbados. In 1979 there were 3 chopper harvesters in operation in Barbados. At that time, McGregor et al. (1979), after carrying out a detailed technical and socio-economic evaluation of the industry, re-iterated the need for mechanization but suggested a controlled increase in the number of chopper harvesters from 3 to 25 over the 10 year period, 1980-1989.

To date, however, the acquisition of chopper harvesters has proceeded at a rate nearly 3 times that recommended. In the 3 year period, 1980-1982, 18 additional chopper harvesters and ancillary equipment have been brought into the island. At an estimated cost of BDS $500,000 per harvester package, this represents an alarmingly large capital investment (of the order of $9 million) in the harvesting operation over the very short period of 3 years. Of particular significance also is the fact that, instead of the annual output per machine increasing from 6,500 tonnes to 10,000 tonnes as suggested by McGregor et al. (1979), it has fallen, apparently below the 6,000 tonnes level. This year harvesting machines have been operated at less than 30 percent of their rated field capacities, idle time in the field has been of the order of 30 percent of available working time, and factory retention time and total turn-around-time of cane transport vehicles have both been rather excessive (Harvey, 1982).

This study seeks to address the problem of gross under-utilization of this already large and rapidly increasing fleet of sugar cane combine harvesters and associated cane transport equipment. There seems to be little point in continuing to inject large capital sums into the cane harvesting and handling process until optimum or near optimum performance and efficiency levels are achieved with the mechanical equipment already in existence.

1.3. Approach to the Study

The approach chosen to study the mechanical harvesting and handling of sugar cane in Barbados (or more specifically, combine chopper harvesting) is to use a combination of computer simulation and Operations Research techniques. This involves firstly, development of simulation models to accurately represent existing systems and secondly, experimentation with these models so as to simulate and evaluate alternative system operating procedures.

The overall inefficiency of mechanical harvesting systems probably has as much to do with the inefficiency of the cane transport and factory yard operations as it has to do with under-utilization of combine harvesters in the field. Essentially, therefore, two computer simulation models will be developed; a field operations model (FIELDOP) which will simulate in-field operations as well as cane transport operations; and a factory yard operations model (FACYARD) which will simulate the activities involved in the handling of the cane as it passes through the factory yard. Activities included in the first model would be the loading of cane transport vehicles and their travel to and from the factory, while those included in the factory yard model would be queuing of transport vehicles at the factory, weighing, unloading, taring (if done) and vehicle departure from the factory.

CHAPTER 2

OVERVIEW OF THE BARBADOS SUGAR INDUSTRY

2.1. Introduction

Production of cane sugar has been a major activity in Barbados ever since the days of colonization, when the British established the industry primarily as a cheap source of sugar for the British empire. The country was subdivided into a large number of production units called plantations, each of which was managed by a British owner or his appointee and staffed with cheap local labour. From its inception, therefore, the industry was export oriented and for a long time, it was foreign owned and dominated, with benefits from the sale of sugar accruing to Britain rather than to Barbados.

Over the years, the ownership structure and technological and economic character of the industry have changed significantly. More than 99 percent of the sugar lands and all of the sugar factories are now owned by Barbadians. Some of the plantations (now referred to as 'estates') have been amalgamated in order to take advantage of economies of scale with regard to improved technology. Cane production activities are almost fully mechanized and, in light of a declining harvest labour force, efforts are now being made to mechanize the harvesting operation. The final product of the industry is currently sold through a sophisticated system of largely pre-negotiated markets and the returns from these sales has made the sugar industry a major foreign exchange earner for Barbados.

2.2. The Role of the Sugar Industry in the Barbadian Economy

Until about 1960, sugar was undeniably the mainstay of the Barbadian economy. Since then, however, the industry's share of gross domestic product and of exports has dwindled, due both to the decline of sugar production and the growth and development of other sectors, principally tourism and manufacturing. In the mid 1950s, sugar's contribution to GDP was 33 percent (Barbados Economic Report, 1960). This fell to approximately 20 percent in the early 1960s and in the last three years has been around 6 percent (Barbados Economic Report, 1961-1981). As far as exports are concerned, the share of sugar and sugar-based products (rum and molasses) has declined less sharply from around 95 percent in the late 1950s to about 40 percent in recent years (Barbados Economic Report, 1950-1981). Despite this apparent decline in national importance of the sugar industry, however, the industry is still considered to be playing a very crucial role in the overall economic activity of Barbados.

It has been estimated that in 1977 some 7,500 persons were gainfully employed, on a regular or seasonal basis, by the sugar industry, representing about 7.5 percent of the total national work force (Dept. of Labour, 1979). Beyond this there are considerable backward and forward linkages, as well as multiplier effects, arising from the expenditure of incomes earned in the sugar industry itself and from related activities (McGregor et al., 1979). Persaud (1973) estimated that, in 1968, 20 percent of the materials and 60 percent of the services purchased by the sugar sector as a whole, accrued to local incomes.

Certain firms engaged in heavy engineering and industrial activity (for instance, the Barbados Foundry and Central Foundry), owe their existence and development largely to the equipment and machinery needs of the sugar industry, particularly of the processing activity. In addition, the sugar industry generates a substantial local demand for tractors and ancillary agricultural equipment, transportation and automotive equipment, materials handling equipment, and repair and maintenance services associated with such equipment. It is estimated that such backward linkages accounted for approximately BDS $6 million of local income in 1977 (Barbados Economic Report, 1978).

Direct forward linkages emanating from the sugar industry include distilling and, to a lesser extent, food and beverage processing and manufacture of livestock feeds. Out of a total production of 23 million litres of molasses in 1976, 16 million litres were used to manufacture rum and a small quantity went into animal feed manufacture. That year, the two major Barbadian distillery companies produced 22 million proof wine litres of rum of which 8 million litres, worth BDS $4.1 million, were exported (Barbados Economic Report, 1976).

Apart from direct backward and forward linkages, income is generated by the multiplier effect arising from the spending of income earned in the industry. Persaud (1973) has reported that income generation has tended to be relatively larger in the sugar industry than in other sectors of the economy with the exception of the distribution sector. Based on figures for the year 1968 (the most recent available), he estimated sugar's share of the direct value added in the final sector demand to be 67 percent in sugar cane production and 8 percent in cane processing, or about 52 percent for the sector as a whole. Comparative figures for other sectors are 55 percent in distribution, 42 percent in non-sugar manufacture, 35 percent in non-sugar agriculture, 33 percent in construction and 19 percent in the tourist industry (Barbados Economic Report, 1969).

As far as foreign exchange earnings are concerned, the sugar industry stands second only to tourism (Barbados Economic Report, 1980). In terms of stability, however, it seems to be the general opinion of most Barbadians that the sugar industry offers considerably more long-term financial security and reliability than does the tourist sector. While the former is well known to be vulnerable to volume and price fluctuations, it seems somewhat far-fetched to conceive of a situation in which the entire industry could become severely shrunken over the short term. On the other hand, the tourist industry is easily interrupted in the short term, the inflow of tourists being extremely sensitive to natural disasters and political disturbances not only in Barbados, but in any of the neighbouring Caribbean countries, or merely to the fear of such events occurring, and to economic trends in the developed countries of the world.

Finally in assessing the role of the sugar industry in the Barbadian economy, there are a number of socio-economic benefits that cannot be ignored. For example, it may be argued that, whereas in the 300 years of British colonial domination, the sugar industry, being geared towards the needs of the British Empire, may have been a net beneficiary of social and economic infrastructures. Today, it probably is a net contributor, mainly as a result of the imposition of various Government levies.

2.3. Structure of the Industry

The present structure of the Barbados Sugar Industry has evolved from the plantation system of agriculture to which the country was subjected during nearly 300 years of British colonization. In those days, the main commercial unit of production was the plantation which was characteristically owned and managed by a British master and staffed by black field workers. Today the basic commercial land unit is essentially unchanged but former plantations are now called 'estates' and estate workers are represented by vibrant workers' trade unions.

Sugar cane processing was carried out by numerous small individual sugar mills with little or no central control or direction. Marketing too was a simple process, marketing activity being confined to transporting the final product to British refineries. In recent years, however, the structure of the industry has changed considerably and today well defined and quite sophisticated production, processing and marketing sectors are discernible.

2.3.1. The Production Sector

In Barbados there are two modes of sugar cane production: estate production and small-holder production. An estate is defined as any holding of 5 or more arable hectares, all other holdings being classified as small-holdings. Currently there are 134 estates cultivating approximately 15,500 arable hectares (115 hectares per average estate unit) and some 10,000 small-holdings cultivating approximately 3,200 hectares of cane (McGregor et al., 1979).

Unlike the case in several other Caribbean cane-growing territories, there is little expatriate ownership in the Barbados sugar industry and, in fact, only four estates (the equivalent of 620 arable hectares) are owned by non-Barbadians (McGregor et al., 1979). Despite this, however, absentee ownership is still a prominent feature of the industry and only 25 estates (2,140 arable hectares) can be regarded as substantially owner-managed. The attorney system, a legacy of the days of foreign absentee ownership, has been retained as the core of the management structure. An attorney represents the interests of the owners of an estate and presides over the financial and other policy matters of the estate. Subordinate to him there is a manager responsible for the day-to-day running of the estate. In Barbados, a single attorney is usually responsible for several estates, rather than just one and, in fact, four attorneys now control 34 estates, comprising some 6,500 arable hectares. Estates and small-holdings are located throughout the country as shown in Figure 2.1.

Small holders are essentially part-time cane farmers, yet, in aggregate, they account for a very significant 15 percent of total cane production in Barbados (Figure 2.2). They constitute the bulk of the full-time estate labour force during peak labour demand periods, and most of them find additional employment outside agriculture. In 1971, the National Agricultural Census indicated that as much as 70 percent of fill-time estate workers cultivated their own cane that year. However, a more recent survey conducted by McGregor et al. (1978) has put this estimate at 50 percent.

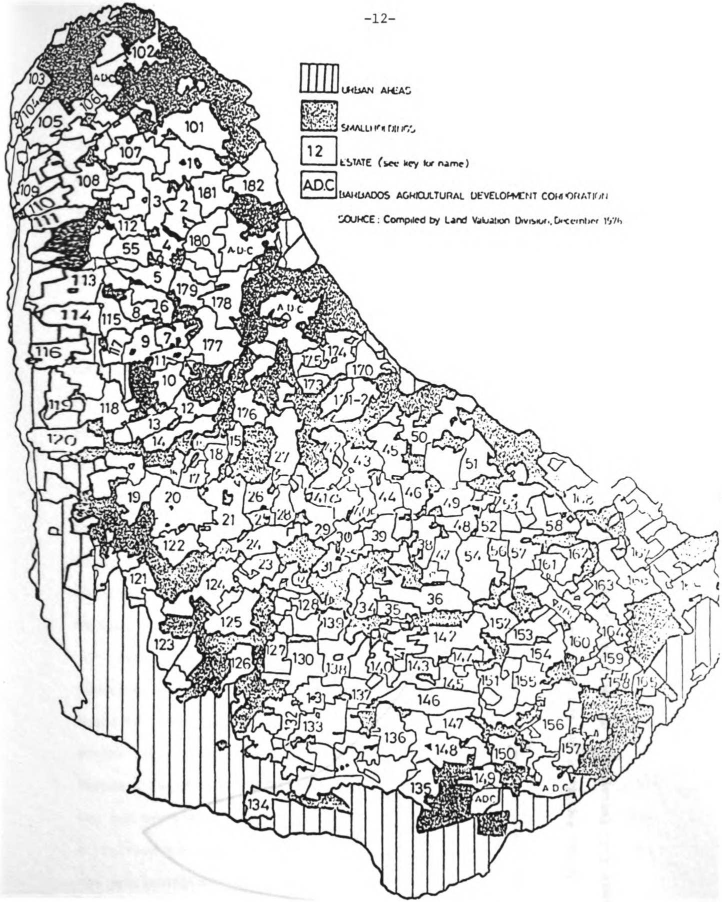
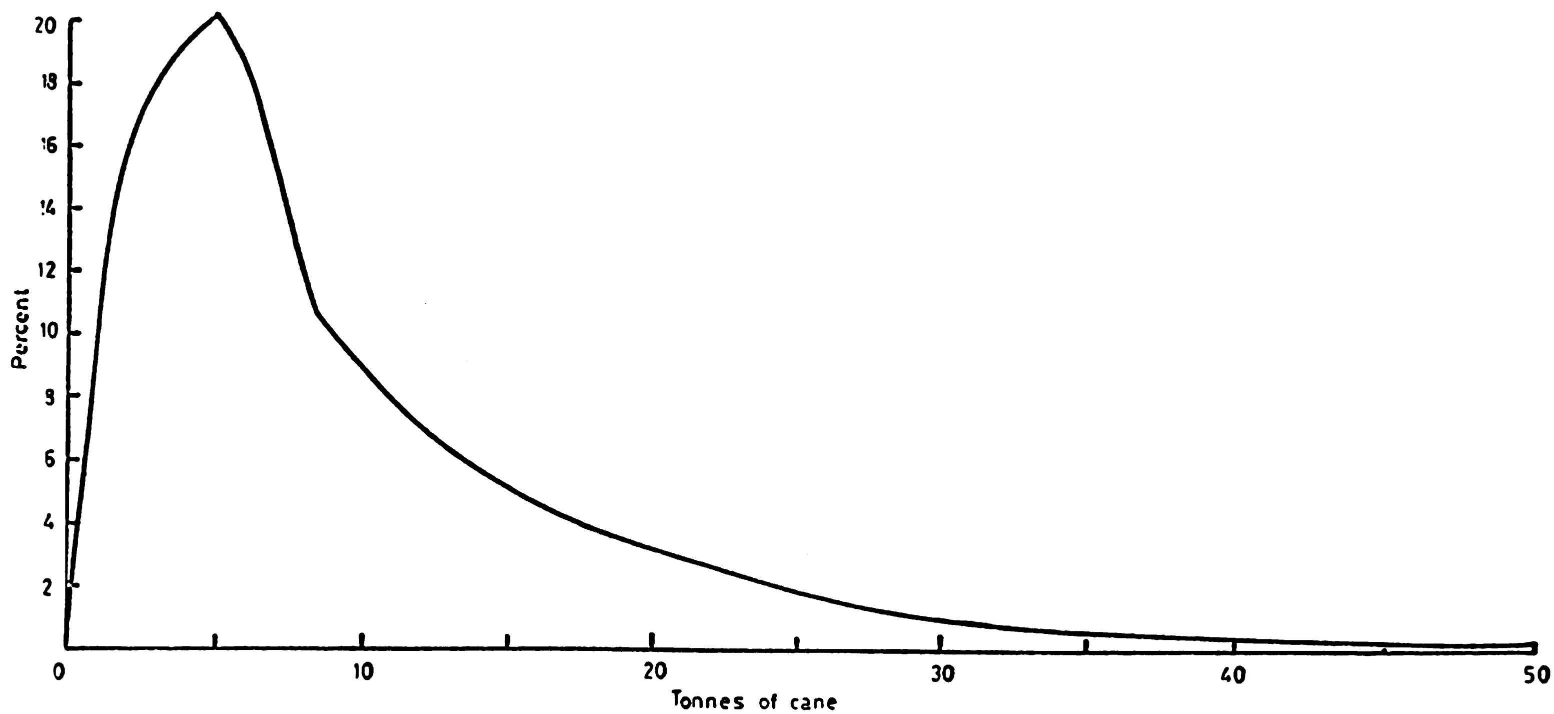


Figure 2.1. The location of estate and small holder land.



SOURCE: Records of the Barbados Sugar Factories Limited.

Figure 2.2. Percentages of small holders producing various amounts of cane.

2.3.2. The Processing Sector

The manufacture of cane sugar in Barbados began in the 1640s following the introduction of a model of a sugar mill and some skilled artisans from Brazil (Barbados Sugar Review, No. 47, 1981). The early factories were extremely inefficient, the output per factory in the decade 1700-1709 averaging just 15 tonnes sugar per year with a tonnes cane/tonnes sugar ratio of 18 to 20.

In 1709, there were 485 sugar mills, 409 of which were driven by wind and 76 by animal power. Thereafter the processing of cane remained technologically stagnant until the 1840s when the first steam plant was introduced (Barbados Sugar Review, No. 47, 1981). This switch to steam-powered plants generated a steady decline in the number of factories and by 1958 only 26 mills remained.

Sugar factories in Barbados are still relatively small and much of their equipment is outdated. Maintenance of the sugar mills has, therefore, posed increasingly difficult problems over the last 20 years and, as a result, the number of mills kept in operation has been progressively reduced from 26 in 1958 to 17 in 1969.

Prior to 1970, sugar factories were operated largely by individual owners or private individual companies and closures of factories were based on individual financial decisions, rather than on the interests of the industry as a whole. In June 1970, however, a single company, Barbados Sugar Factories Limited (BSFL), was incorporated to collectively own and operate all existing factories. With the birth of this company, a rigorous rationalisation programme (aimed at planned restructuring of the processing sector of the industry) ensued, leading to the further closure of the smaller, marginal and uneconomic mills and the modernization and improvement of those mills that were retained. During the rationalisation process, the island was divided into three zones; North, Central and South and two factories were allocated to serve each zone. To date five of the original sugar factories are in operation; two each in the South and Central zones and one in the North. In addition a new modern sugar factory has been constructed in the North zone and was commissioned during the latter half of the 1982 harvesting season. The erection of this new factory represents a major capital injection into the processing sector since the last factory established was built as long ago as the year 1920. With these six factories in full operation, the theoretical throughput capacity of the processing sector is in the region of 480 tonnes per hour or 11,500 tonnes per 24 hour working day.

The Barbados Sugar Factories Limited holds majority shares in three service companies associated with the processing activity: the Barbados Molasses Terminal Limited (97%), the Sugar Terminal Limited (56%) and the Sugar Transport Limited (100%). The BSFL is primarily a grower-owned processing company whose ordinary shares are tied to ownership of sugar cane lands. All but three estates hold shares in the company (McGregor et al., 1979).

The BSFL is the sole purchaser of all sugar cane grown on the island. After deducting monies for industry-wide fixed expenses, the factory company retains 26 percent of the revenue from the sale of sugar and molasses to cover processing costs, and the rest is paid to the growers.

In Barbados cane farmers are paid for their canes on the basis of weight (rather than sucrose content as is done in several other cane growing countries including Australia). However, at the end of the season, each factory adjusts the final cane price on the basis of its average sugar recovery from the cane. The final cane price, therefore, differs between factories and it is not uncommon for this difference to be in the region of $2 per tonne. During the 1982 harvesting season, efforts were made to reflect the extraneous matter content of cane delivered by a grower in the price received for that cane. Throughout the season, extraneous matter determinations were done on random samples of cane delivered to each factory each day, so that appropriate penalties could be included in the price paid for cane having an extraneous matter content in excess of 3 percent by weight.

On the international sugar scene, the Barbados Sugar Industry reportedly stands high with respect to overall operating proficiency and final product quality (McGregor et al., 1979). In terms of energy utilization, the industry's processing sector may even be unique. Unlike cane sugar factories in most other parts of the world, those of Barbados operate exclusively on bagasse (a by-product from the mills) and some factories also manage to produce a considerable bagasse surplus which has the potential of being used for the manufacture of soft wood laminates.

2.4. Markets for Barbadian Sugar

Like most primary industries of countries emerging from extended periods of foreign colonization and domination, the Barbados Sugar Industry is primarily export oriented. Of the average annual production of 112,000 tonnes over the five year period 1973-77, some 98,000 tonnes (or 87%) were exported with only 15,000 tonnes (13%) being disposed of on the domestic market (McGregor et al., 1979). The main export markets were the European Economic Community (EEC) and the World Market.

2.4.1. The European Economic Market

At present, the European Economic Community is the main export market for cane sugar produced by the African, Caribbean and Pacific (ACP) group of countries, of which Barbados is a member (McGregor et al., 1979). Prior to 1975, there was a Commonwealth Sugar Agreement (CSA) which fixed export quotas for Commonwealth sugar producers, thus providing a guaranteed and sheltered market for most of the sugar produced. In February of 1975, the CSA was superceded by a Sugar Protocol agreement signed at the Lomé Convention of that year. Under the terms of the Protocol agreement, the EEC is committed to purchase from Barbados 49,300 tonnes, white value (about 53,600 tonnes raw value) of sugar annually (Barbados Sugar Review, No. 41, 1978). Since the Protocol is supposed to be valid indefinitely (unlike the Convention itself which is subject to re-negotiation every five years) then, in theory, it represents an assured outlet for Barbadian sugar.

The EEC is reportedly self sufficient in beet sugar and is, on balance, a net exporter to the World market (McGregor et al., 1979). In effect, therefore, the cane sugar imported by the Community from the ACP countries pursuant to the Sugar Protocol of the Lomé Convention, is re-exported. Despite this, the Protocol agreement has so far been totally honoured (probably for political reasons) and appears to be relatively reliable. It is worth noting, however, that a large British refinery concerned mainly with the refining of ACP produced sugar, has recently ceased operation and initial implications are that some ACP countries may have to seek alternative markets for a sizeable quantity of their raw sugar.

African, Caribbean and Pacific countries exporting sugar under the Lomé Sugar Protocol receive a guaranteed price which is negotiated annually within the price range obtained in the EEC while taking consideration of all relevant economic factors (Barbados Sugar Review, No. 41, 1979). Given normal market conditions, this price tends to be substantially higher than free World market prices. However, since Lomé prices are indexed to EEC price ranges, annual fluctuations in the price received by ACP producers are more strongly influenced by the EEC supply and demand schedules than by production costs in the ACP countries themselves. The net result of this is that the guaranteed Lomé price has not risen as rapidly as production costs have in the Barbados Industry. The indication is, therefore, that it is essential for the Barbados Sugar Industry to keep its production cost trend as closely paralleled as possible to the movement of production costs in the EEC, in order to maintain present profit margins. This implies increased productivity of existing sugar lands and decreased production costs and, since harvest labour costs are a major component of production costs, increased harvest mechanization.

The actual economic return to Barbados from sugar sales to the European Common Market reflect not only the annually negotiated Protocol price but also any premia obtained from individual purchasers within the Community (McGregor et al., 1979). The largest purchasers of

Barbadian sugar within the EEC have been the United Kingdom and Ireland. Sugar supplied to refineries in these two countries commands a premium over the Lomé negotiated price.

2.4.2. The World Market

In global terms, the free (World) market represents a residual outlet for the relatively small proportion of the world's sugar which is not consumed in the producing countries or traded under pre-negotiated market arrangements such as the Sugar Protocol of the Lomé Convention. Due to the residual nature of the world market, cyclical imbalances between supply and demand (mainly as a result of weather stimulated supply variations) often generate wide fluctations in the price of 'free' sugar.

Sale of sugar on the world market is governed largely by the International Sugar Agreement (ISA). Under the terms of reference of this agreement, Barbados is regarded as a small exporter and is granted an annual export entitlement of 70,000 tonnes of raw sugar. This entitlement is not subject to quota adjustments, neither is Barbados required to observe the ISA's stock provisions with which larger exporting countries must comply (Barbados Sugar Review, No. 41, 1979).

In recent years, the main world market outlets for Barbadian sugar have been the Canadian and U.S. markets.

Not all of the sugar exported to North America is in the form of the crystalline final raw product. A significant portion of the exports to the U.S. and the bulk of the exports to Canada are in the form of fancy molasses, (a specialized intermediate product of the processing activity) which normally commands a premium price over raw sugar (Ministry of Finance, 1975-81).

The 1977 International Sugar Agreement established a target price range of 24 - 47 U.S. cents per kilogram of raw sugar. The average ISA free market spot price for raw sugar for the period 1977-1979 was 17.90 U.S. cents per kilogram, a price which was below the average financial costs of production of most producers in the world (McGregor et al., 1979). Owing to the large excess supply of world sugar over demand, however, even the lower end of this target price range was not reached until 1981 when the price reached 31.25 U.S. cents per kilogram.

2.4.3. The Domestic Market

The domestic consumption of sugar in Barbados averages 15,000 tonnes annually (McGregor et al., 1979) and, with a population of about 250,000, this works out to be an annual per capita consumption of 60 kilograms. This figure is high by world standards (OECD/OCDE, 1975, 1979) and, with the demand for sugar in Barbados practically income inelastic, one cannot envisage any growth in domestic demand for sugar, except a gradual response to total population increase.

Before 1976, factories received a fixed price of BDS $376.17 per tonne 96° Pol, or 19 U.S. cents per kilogram, for all grades of sugar. Since then, however, ex-factory prices for domestic sales have risen substantially. In 1977, price differentials between all grades of sugar (Browns, Yellows and Straws) were established to reflect product quality and the general level of ex-factory prices even rose above the prices obtained for foreign sales other than to the European Economic Community.

Currently confirmed potential sales of the Barbados Sugar Industry total some 139,000 tonnes, raw value; (54,000 tonnes to the EEC; 70,000 tonnes through the ISA and 15,000 tonnes for domestic consumption). McGregor et al. (1979) have estimated that, if the world sugar prices were to exceed 33 U.S. cents per kilogram, Barbadian exports to the free market could well surpass the 70,000 tonnes allowed under the ISA agreement. Unfortunately, however, the Industry has not been able to fully exploit the available sales opportunities over the last few years. In 1979, 1981 and 1982 sugar production was only 112,000, 96,000 and 96,000 tonnes representing shortfalls in potential sales of 20 percent, 31 percent and 31 percent, respectively.

2.5. History of Mechanical Harvesting of Sugar Cane in Barbados

Mechanical harvesting of sugar cane was first introduced to Barbados in 1968 when two machines, a Toft J-150 and a Crichton, were imported from Australia. Both of these machines were wholestick harvesters which cut the cane at the base and deposited it in piles for subsequent pick-up either manually or by a mechanical loader. These machines were operated in both burnt and green cane but, even in burnt cane (for which they were primarily designed) their performance was unsatisfactory. Both machines were set on 1.5 m wheelbases which were not only narrower than the inter-row spacing of the cane but were inadequate for the rolling terrain and stony conditions that existed in most of the fields at the time. The machines were reportedly very little used (McGregor et al., 1979) and, since no significant efforts were made to adopt field conditions and inter-row spacing to the design constraints of

the harvesters, it is doubtful whether they were ever really subjected to a serious field evaluation.

In 1970, a Cameco wholestick harvester and a push-pile loader were imported from the U.S.A. The harvester was large and proved to be too cumbersome for operation in the small, irregularly shaped Barbadian cane fields. The push-pile loader, however, generated considerable interest among the larger cane growers.

In 1971, a decision was taken to switch from wholestick to chopper-type cane harvesters. That same year, two chopper harvesters, a Toft CH-364 and a Don Mizzi 741, were imported from Australia. The following year, a second Don Mizzi 741 was brought in and in 1973, a Don Solo chopper harvester was imported. All of these machines were designed to operate in burnt cane and controlled burning of cane was, therefore, a prerequisite for their use.

The Toft CH-364 was a rather large, self-propelled combined harvester, well furnished with engine power. It was a quick cutter but, under the stony field conditions that existed at the time, numerous problems were experienced, particularly with the machine's cane elevation system. Its wheelbase, though wider than that of the wholestick harvesters, was still too narrow and even on relatively gentle slopes, lateral stability was a problem.

The Don Mizzi harvester was essentially a cane base-cutting, elevating and cleaning mechanism attached to a reversed L-shaped frame, on to which a standard 60 kw agricultural tractor was mounted. The drive train of the tractor was linked to the main drive shaft of the harvesting mechanism by means of a duplex chain and sprocket coupling.

Tractive power, as well as mechanical and hydraulic power for the moving parts of the harvesting mechanism, were derived from the power unit of the tractor. The resulting combination was a relatively compact, self-propelled unit set on an extended wheelbase 3.7 m in width. Like the Toft CH-364, the Don Mizzi 741 machine delivered cane to the left side only, making two-directional cutting impractical in the smaller cane fields.

The Don Solo chopper harvester imported in 1973 was a more compact, integrally assembled, self-propelled version of the Don Mizzi with the capability of delivering cane to either the right or left of its direction of travel. On account of this, it was theoretically more suited for work in the smaller cane fields. However, because this machine was set on a narrow wheelbase of just 1.5 m, and because most of the smaller fields are located on sloping and undulating terrain, machine stability during operation became a major problem.

Among the machines mentioned above, the Don Mizzi 741 was undoubtedly the most satisfactory, largely because of the extended width of its wheelbase and because concerted efforts were made to prepare the fields for mechanical harvesting according to the guidelines suggested by Baxter, 1969. By the 1973 harvesting season, many of the teething problems associated with this machine had been overcome, and a well organized and technically efficient mechanical harvesting system had been built around the harvester. Just then, however, two independent studies conducted by Chase and Eavis (1972) and Hudson (1972) showed that burning of canes at harvest time reduced the organic matter content of the soil to alarmingly low levels and caused a significant reduction in subsequent crop yields. In addition, reports from the Entomological Division of the Ministry of Agriculture indicated that the populations of predators, which were heavily relied upon for biological control of economically important pests of sugar cane, were likely to be significantly depleted if burning continued. Based on these findings, burning of sugar cane prior to harvesting was outlawed.

Following this, efforts were made to adapt the Don Mizzi system to green cane harvesting but the harvester's unsuitability to this task prevailed and, in 1974, the Don Mizzi system was finally abandoned. Nonetheless, the experience with the Don Mizzi program proved to be very valuable. Not only did it demonstrate the applicability of chopper harvesting to Barbados, but it also provided a foundation of knowledge from which more recent chopper harvester operators were able to benefit.

In 1975, two Toft 300 chopper harvesters, reported to be capable of handling green cane, were brought into Barbados by individual cane producers. Based on the performance of these, two more chopper harvesters, one Toft 4000 and one Massey-Ferguson 205, were imported by agricultural machinery distributors in 1979 for contract harvesting operations. Between 1979 and 1982, 17 additional green cane chopper harvesters, 1 Massey-Ferguson 305 and 16 Toft 6000 machines, have been brought into the country. In terms of field operating procedures, the Massey-Ferguson and Toft cane harvesters are quite similar but, in terms of design, the Massey-Ferguson machines rely heavily on mechanical drives and linkages while the Toft machines are almost exclusively hydraulically driven.

The rapid increase in the number of chopper harvesters in Barbados over the last three years has occurred without a corresponding rapid

development of machine management capabilities and without adequate reorganization of cane receiving facilities at the factory yards. This has resulted in rather inefficient use of most of the individual mechanical harvesting units.

In the late 1960s, the Barbados Sugar Producers Association, inspired by the need for a harvesting system specifically suited to Barbados conditions, initiated development of a wholestick machine system in collaboration with a British firm, McConnel Engineering. The first prototype cutter began working in 1972. This machine, which subsequently became known as the BSPA/McConnel Stage I, cut the cane at the base and left it in a swath along the row for manual cleaning and loading. Seven additional Stage I machines were introduced in 1973 and by 1976 some 37 of these units were in private ownership. Owing to the large number of workers required to work behind these machines as retrievers, machine productivity was very low and probably for this reason, most of the machines were little used.

In an effort to eliminate the heavy labour requirement behind the Stage I, a BSPA/McConnel Stage II machine was developed, the first one being used in 1975. This was essentially a cleaner-piler which picked up the swath formed by the Stage I cutter, removed most of the cane tops and trash, and deposited the cane in piles for final pick-up by a mechanical grab loader. By 1979, seven of these machines were privately owned, mainly by the larger estates. They, too, were used very little and most of the Stage II owners and potential owners have now invested in cane combine harvesters.

The Stage I machine has been retained and further refined by a local firm called CARIB Enterprises. The current model, now known as

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the CARIB cane cutter, is a vast improvement on the original Stage I prototype. The most major modification was mounting the cutting mechanism on a reversed, 4-wheel drive tractor so that considerably more weight is now on the front end of the machine, and traction and stability are greatly improved. Based on observations during the 1982 harvesting season, the CARIB machine seems to have a lot of potential for work in the more hilly central and eastern areas of the country that are not accessible to the larger chopper harvesters.

CHAPTER 3

LITERATURE REVIEW

3.1. Introduction

Tomlinson (1973), in an assessment of the problems of the Caribbean sugar industry, highlighted the need for greater efficiency in organizing and planning the use of harvesting equipment and proposed that the techniques of Operations Research could be found useful in this respect.

Operations Research, as described by the Operations Research Society of America, 'is concerned with scientifically deciding how to best design and operate man-machine systems, usually under conditions requiring the allocation of scarce resources' (Phillips et al., 1976).

Broadly speaking, the application of Operations Research techniques requires the construction of a model which incorporates all the important characteristics of the system (Shamblin and Stevens, 1974). Boyce (1972a) classifies three types of models; iconic, analogue and symbolic. Iconic models physically resemble the subject of inquiry and are characterized by some scaling effect. Analogue models are characterized by the use of a convenient transformation of one set of properties for another. Symbolic models are characterized by the representation of a system by mathematical or logical symbols and expressions.

3.2. Symbolic and Mathematical Models

Most harvesting systems can be represented by the symbolic model, as illustrated in Figure 3.1, and can be generally grouped as closed circuit transport systems (Boyce, 1972b). In general, a closed circuit transport system can be broken down into two separate sub-systems, one located at the field and the other at the installation (factory, mill or other facility). Each sub-system can be represented by a queuing model, in which transport units queue at the field and factory awaiting service. The length of time each arriving unit must wait in line (queue) for service depends on the number of other units already in the queue, the service rate (or service time) and the rate of arrival at the queue (Saaty, 1957). In a real life system, arrival and service rates are not constant but subject to variation about a particular mean. The successful use of mathematical models to represent real queuing systems, therefore, depends primarily on the identification of the form of the probability distributions which best represent the actual arrival and service rate distributions (Page, 1972; Phillips, 1976; Hillier and Lieberman, 1974).

In a general discussion on the use of mathematical models to describe phenomena in agricultural systems, Demichele (1976) proposed three general forms which could be used, depending on the state of knowledge (Figure 3.2). Based on the system being studied, these forms may be represented by different statistical distributions. Hahn and Shapiro (1967) suggested that, in the engineering context, there are often insufficient grounds for choosing a specific model. They indicated that Figure 3.3 (adapted from E.S. Pearson, University College, Brandon) may

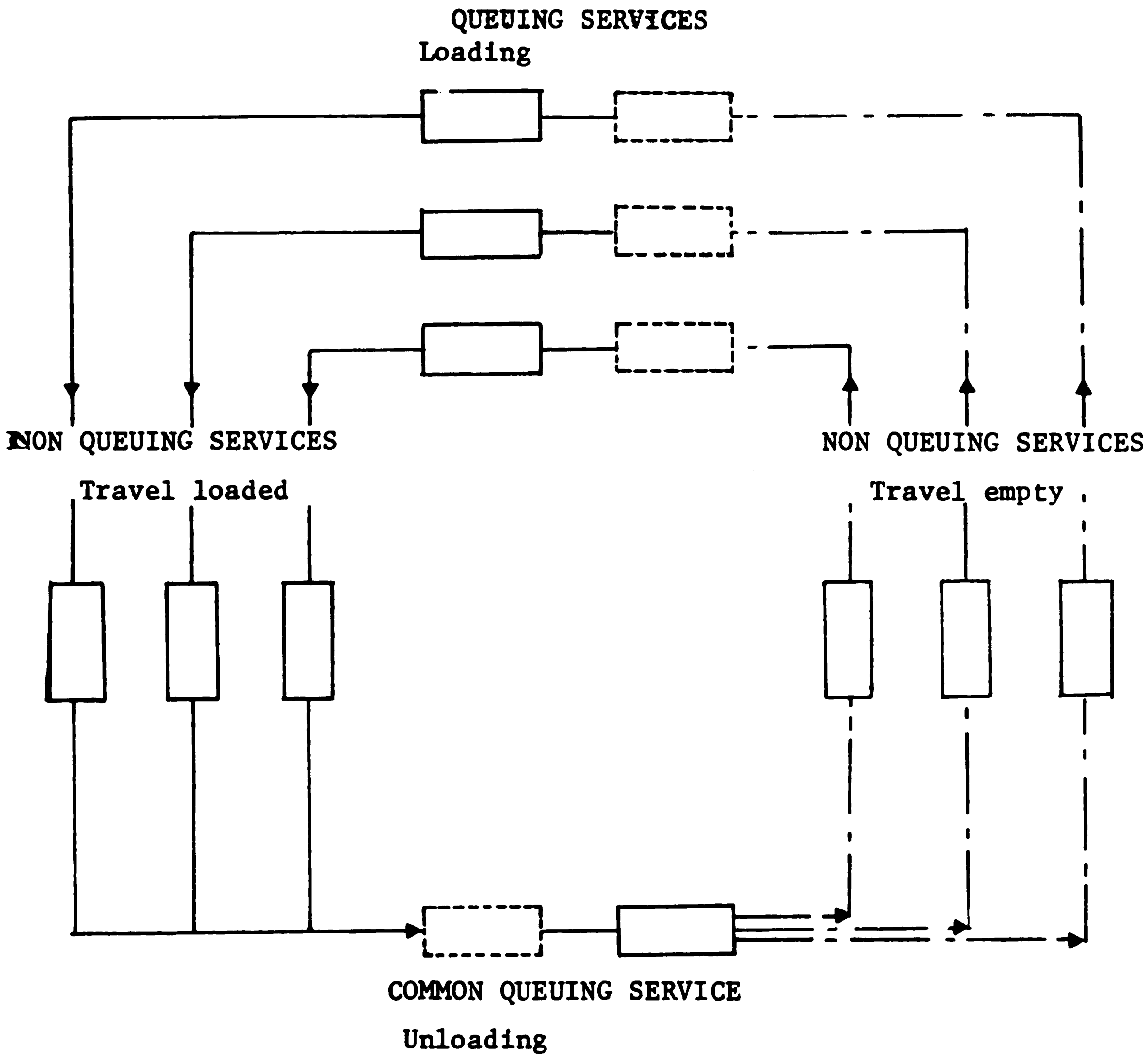
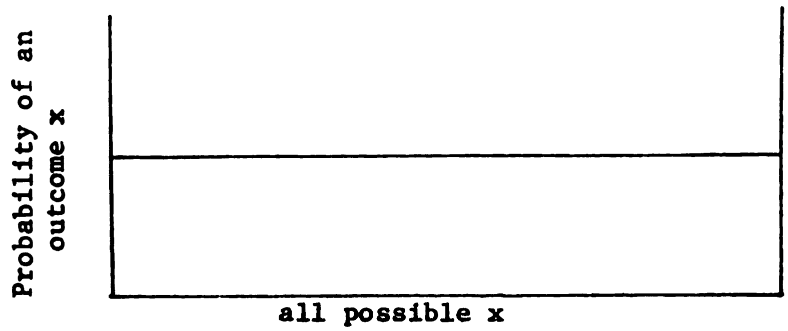
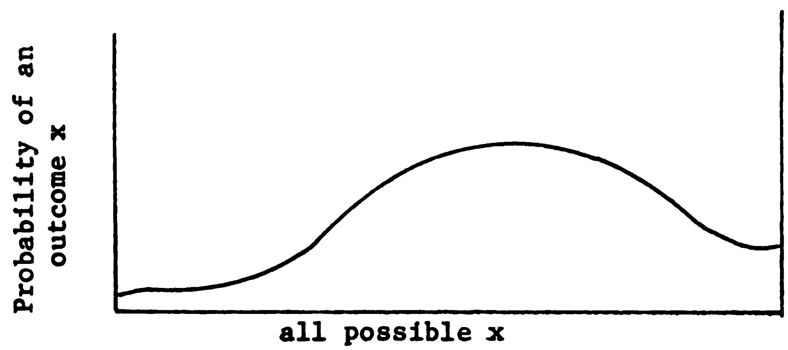


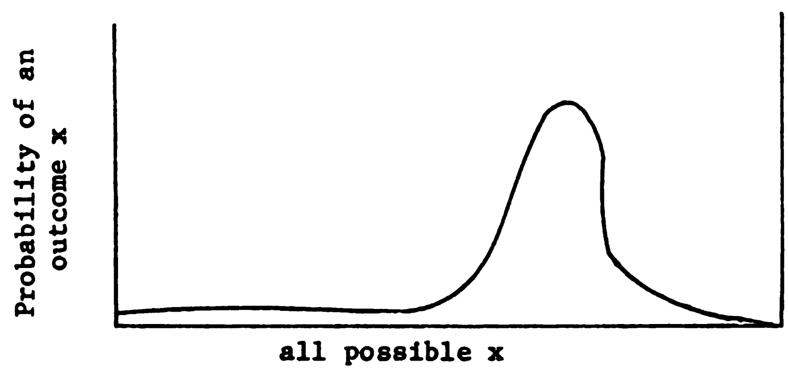
Figure 3.1 Symbolic model of closed circuit queuing system



(1) The distribution function of a system where nothing is known



(2) The distribution function of a system where some things are now known



(3) The distribution function of a system where most things are known

Figure 3.2 Generalised models representing the behaviour of systems

Source: Demichele, (1976).

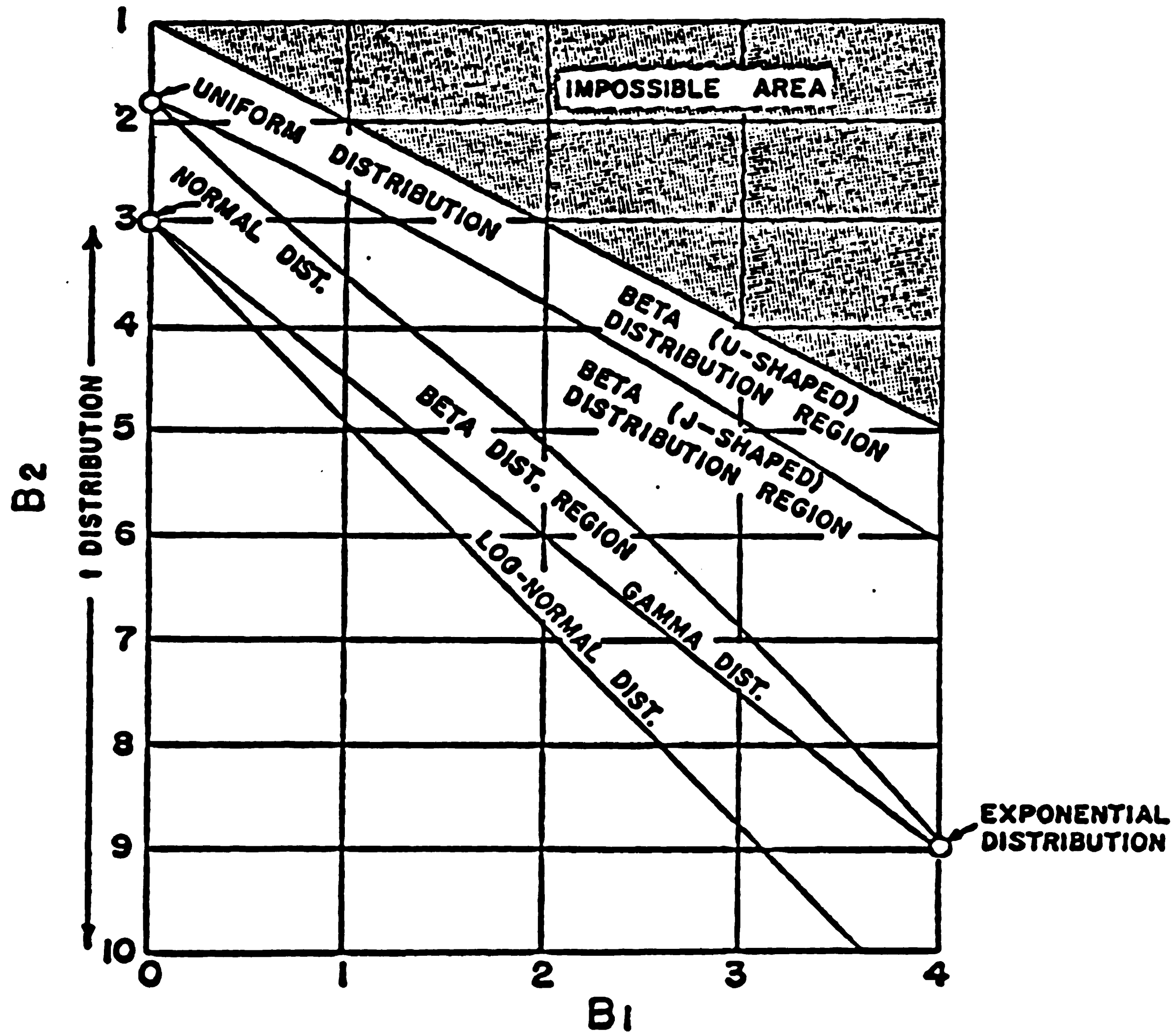


Figure 3.3 Regions in the (B1,B2) plane for various distributions

be used for such a selection. The values of B1 and B2, the square of the standardized measure of skewedness and the standardized measure of peakedness, respectively, can be estimated using equations (1) and (2) below. The estimates so obtained are, however, very sensitive to a few extreme observations and should, therefore, be used with caution, particularly in situations where the number of observations is less than 200. On account of these factors, it is generally desirable to set up a frequency table to enable the fitted distribution to be compared with the observed data.

$$B_1 = b_1 = |M_3/M_2)^{3/2}|^2 \ldots \qquad (1)$$

$$B_2 = b_2 = M_4/(M_2)^2 \ldots \qquad (2)$$

where

$$M_2 = 1/N \sum_{i=1}^{N} (X_i - \bar{x})^2 \ldots \qquad (3)$$

$$M_3 = 1/N \sum_{i=1}^{N} (X_i - \bar{x})^3 \ldots \qquad (4)$$

$$M_4 = 1/N \sum_{i=1}^{N} (X_i - \bar{x})^4 \ldots \qquad (5)$$

x_i = i^{th} value of the variable x

x = sample mean

Hahn and Shapiro (1967) further pointed out that the initial selection of a model should be based on an understanding of the underlying physical phenomena and that a distributional test should be used to evaluate the adequacy of the physical interpretation.

Boyce (1976) indicated that the process of selecting suitable statistical distributions and estimating the appropriate parameters could, in some cases, involve a virtually impossible sampling task if the real system were operating in an unsteady and/or erratic way. He further suggested that the use of an optimistic, a pessimistic and a most likely estimate of the particular quantity of interest, based on field samples, might provide a basis for estimating the parameters of a selected distribution.

Dumont and Boyce (1972) described three methods of fitting three suitable distributions to observed work time data for two agricultural unit operations; transport loading and combine harvesting: These are as follows:

(1) the method of maximum likelihood for the Gamma distribution,

(2) the method of matching moments for the Beta distribution, and

(3) the method of matching percentiles for the Johnson S_B distribution.

The Chi-squared test statistic was used to test the goodness of fit for each set of parameters determined. Their general conclusion was that, in practice, any one of the three distributions would be acceptable for use in simulation modelling to represent the distribution of transport loading times, but that the Gamma distribution seemed incapable of providing an acceptable fit for the combine harvesting times data.

Bouland (1967) conducted a study of truck queues which formed at country grain elevators in the U.S.A. and found that transport unit arrival rates could be described by Poisson distributions for rates of less than 35 arrivals per hour, and by Uniform distributions for rates exceeding 35 arrivals per hour. Service times of weigh scales and unloaders were found to fit Erlang distributions. The probability density functions of these distributions are as follows:

The Poisson distribution

$$f(x) = e^{-M} M^{x} \quad x = 0,1,2. \ldots \quad (6)$$

where

x = value of discrete variable

M = expected value = variance

Source: Bhattacharya and Johnson, 1977.

The Discrete Uniform distribution

$$f(x) = 1/N \quad x = 1,2,\ldots\ldots,N \ldots \quad (7)$$

where

x = value of discrete variable

Source: Bhattacharya and Johnson, 1977.

The Erlang distribution

$$f(x:\eta,\lambda) = (\lambda^{\eta} x^{(\eta-1)} e^{-\lambda x})/(\eta-1)|, x > 0 \ldots \quad (8)$$

where

x = value of continuous variable

λ = scale factor

η = shape factor (restricted to integers)

Source: Manetsch and Park, 1980.

Dumont and Boyce (1972) found that the Gamma distribution, the more general form of the Erlang distribution, gave an adequate representation of transport loading times for various field conditions. The Gamma distribution has the following probability density function.

$$f(x:\eta,\lambda,\mu) = \lambda^{\eta}(x - \mu)^{\eta-1} e^{-\lambda(x-\mu)} \quad \ldots\ldots\ldots\ldots (9)$$

where

$\eta > 0$; $\lambda > 0$; $\mu < x < \infty$; $-\infty < \mu < \infty$ and $G(\eta)$ is the Gamma function given by

$$G(\eta) = \int_0^{\infty} (x-\mu)^{\eta-1} e^{-(x-\mu)} dx \quad \ldots\ldots\ldots\ldots (10)$$

where

x = value of continuous variable

λ = scale factor

η = shape factor

μ = location parameter

Brooks and Shaffer (1971) reportedly developed a mathematical model to predict the output for tipper trucks hauling dirt from an excavation site to a landfill area (Ogilvie et al., 1978). Their approach consisted of six basic steps:

(1) determination of all possible combinations of shovel and truck, each combination being called a state;

(2) measurement of the ability of the shovel to change each state defining the rate of transition between states due to the shovel by the mean service rate;

(3) measurement of the ability of the truck to change each state defining the rate of transition between states

due to the trucks by the arrival rate of the trucks at the shovel;

(4) determination of the net effect of changes by shovel and by trucks;

(5) determination for steady-state conditions, of the percent of time on average that an operation was in any particular state;

(6) calculation of the steady state output of the system by multiplying the service rate by the Production Index (PI), where PI = sum of the percentage of time that the system was in each productive state.

The main objective of this model was to improve the opportunity for the contractor to apply queuing theory in practice by providing a procedure which did not require knowledge of the mathematical rigour of queuing theory, but at the same time provided a method of predicting output, which could be rapidly and easily applied. Based on their model, Brooks and Shaffer (1971) reportedly developed a set of curves for various combinations of the mean service and arrival rates and the number of trucks for simple single server and multiple server systems, as well as systems in which the shovel had a hopper.

Audsley and Boyce (1973) used a mathematical approach of queuing theory to develop models of cyclic transportation systems. In their work, they assumed that service times were independent and identically distributed and could, therefore, be represented by some form of Erlang distribution. They obtained similar results to the production index which Brooks and Shaffer obtained in 1971 (Ogilvie et al., 1978).

3.3. Computer Simulation Models

An approach to the study of large and/or complex systems which is rapidly gaining popularity is computer simulation. Phillips et al. (1975) stated that simulation has become one of the most widely used and accepted tools of systems analysis. Broadly speaking, simulation is a problem-solving technique for defining and analysing a model of a system (Dent and Blackie, 1979). To simulate means 'to duplicate the essence of a system without actually attaining reality' (Rockwell, 1965). Underlying any simulation is a mathematical abstraction of the system which relates various system functions. In a paper on the use of simulation methodology in agriculture, Rockwell (1965) suggested several reasons for using simulation analysis. Most of these reasons have been re-iterated in a more recent work by Naylor (1971). They are as follows:

(1) The system may be too complex for analytical solution in which case, simulation can yield valuable insight into which variables are more important in the system and how these variables interact.

(2) With simulation, it is possible to build in time delays, non-linearities, irregular distributions and discontinuities into the system.

(3) Systems in which time is a critical factor are well suited to computer simulation. For certain types of stochastic problems, the sequence of events may be of particular importance. Information about expected values and moments may not be sufficient to describe

the process. In these cases, simulation methods may be the only satisfactory way of providing the required information.

(4) Simulation can be used to experiment with new situations about which we have little or no information. The simulator permits later decisions to be based on earlier system output as in a dynamic programming framework.

(5) The process of designing a computer simulation model forces the researcher or designer to explicitly describe the system processes and the required data. The knowledge obtained in the design activity frequently suggests changes in the system being studied. The effects of these changes can then be tested, via simulation, before implementing the changes on the actual system.

(6) The process of simulation design is in itself a valuable educational tool and it has been used by many companies as a pedagogic device to help management understand the characteristics of the systems which they control.

(7) Simulation permits us to experiment with systems that, in reality, it would not be possible to experiment with. Through simulation, one can study the effects of certain informational, organizational and environmental changes on the operation of a system by making alterations in the model of the system and observing the effects of

these alterations on the system's behaviour.

(8) Simulation can serve as a 'preservice test' to try out new policies and decision rules for operating a system, before running the risk of experimenting on the real system.

(9) Simulation can often lead to a training device such as a management game. Since the simulation process gives no valuable insights into the qualitative aspects of human decision making, and because of its natural realism, it often becomes possible to convert the simulator into a simulation training device.

(10) Simulation models usually provide better user acceptance than analytic models. The systems user can see the reality of the simulation and thus will usually have more faith in the conclusions from the simulation output.

(11) The interpretation of simulation results does not usually demand a mathematical background on the part of the user.

(12) Monte Carlo simulations can be performed to verify analytical solutions.

(13) Simulation is well suited to sensitivity analysis in which key system parameters are selectively altered to test their contribution to overall system performance.

(14) When new elements are introduced into a system, simulation can be used to anticipate bottlenecks and other

problems that may arise in the behavior of the system.

Computer simulation, as defined by Pritsker (1974), is the establishment of a mathematical logical model of a system and the experimental manipulation of the model on a computer. Development of the model requires an in-depth analysis of the system in order to identify its important characteristics and components. Such components include entities, their attributes and events, which may be defined as follows:

Entities - objects within the boundaries of the system being studied

Attributes - characteristics of entities within the system

Events - occurrences which cause change in the status of the system.

Simulation can be analogue or digital, discrete or continuous, with or without a computer, with or without real time (fast or slow) and with or without a human decision maker in the simulated process (Rockwell, 1965). Digital simulation requires that for each instant of model time, a series of calculations be performed to produce a set of discrete outputs. The reaction of the model to any input function is, therefore, determined by repeating the series of calculations for each instant of time for which the response is required. Analogue simulation requires that model variables simultaneously assume their appropriate values so that parallel recording of these values can reproduce all the important aspects of the system's performance (Link and Splinter, 1970). Generally, the rapid development of high speed digital computer technology, and of simulation languages based on such technology, has made digital simulation preferable.

Hillier and Lieberman (1974) stated emphatically that simulation models need not be completely realistic representations of the real systems, since representing all of the minute details of real systems often leads to excessive programming and use of excessive amounts of computer time for the benefit of a small amount of additional information. These authors further suggested that the behavior of system elements is best represented by theoretical distributions which best fit observed data from which random samples can be drawn. In light of this, an important aspect of simulation modelling is the validation of the model to show that it adequately represents the 'real-world' situation.

Model validation can be achieved by comparing observed 'real-world' system performance data with data generated by the model (Hillier and Lieberman, 1974; Manetsch et al., 1974). Standard statistical tests such as the Student's 't' test for the comparison of two means and the χ^2 and F tests for inferences about variances, can sometimes be used to determine whether the two sets of data are statistically different. These procedures are designed to make inferences about the values of the parameters 'μ' and 's' that appear in the prescription for the mathematical curve of the normal distribution and are collectively known as 'normal-theory' parametric inference tests.

Another useful statistical test which may be used for the comparison of two sets of data is the Wilcoxon Rank-Sum Test originally proposed by F. Wilcoxon (1945). An equivalent alternative version of this test was independently proposed by H. Mann and D. Whitney (1947) and is now known as the Mann-Whitney U Test (Bhattacharrya and Johnson, 1977).

Neither the Rank-Sum nor the U Test is restricted by the assumption that the data are normally distributed and they both test specifically whether two samples drawn from different populations have the same distribution. These tests are non-parametric tests and they can be used for both small and large sample sizes, although some test power is lost as the sample size decreases (Bhattacharrya and Johnson, 1977).

3.4. Sugar Cane Simulation Models

Simulation models have been used for about 15 years to study farm machinery systems. Specific areas of application have been: predicting expected returns (Sowell et al., 1967); analysis of specific cropping systems such as cotton production (Stapleton, 1967); forage harvesting (Coupland and Halyk, 1969); the performance of field machines and transport units for a row crop planting system (Von Bargen and Peart, 1969); the effect of the different harvesting system configurations on closed circuit cyclic transportation systems (Boyce, 1972); silage harvesting (Russel et al., 1977) and sugar cane harvesting. The literature on application of simulation modelling to sugar cane harvesting is examined in some detail below.

Sorenson and Gilheany (1970) developed a model for testing different strategies and decision rules governing the deployment of equipment on a cane plantation in the Caribbean. For this model, time for loading in the field, cane transport travel time for a given distance and unloading time at the factory, were represented as constants, and statistical models were developed for crop rotation, rain and trash, rained-out field conditions, mill capacity and transport unit breakdowns. These authors suggested that, with minor modifications, their program could be used to optimize the length of the cane crop.

Farquhar (1972) discussed the potential of adapting the systems approach in general and simulation in particular, to the analysis of sugar cane production systems, and used a generalized model to highlight some of the complexities of such systems.

Shukla, Chisolm and Phillips (1973) developed a computer program for analyzing harvesting, loading and transportation of sugar cane. The programme reportedly gave good results for the systems studied but was somewhat locale-specific and depended heavily on the coefficients derived from a time and motion study which had been on-going for several years.

Early (1974) used an inventory model to simulate harvesting conditions in the Philippines. The specific objective of this work was to synchronize field and factory operations under conditions of random rainfall. He identified three limitations to his model based on the methodology used in constructing the model, the data used in modelling the system response and the sequencing of rainfall events. Despite these limitations, he concluded, after simulating 10 years of operations, that the existing policy of allocating a daily quota to all farmers, each in proportion to their share of the milling capacity, could be improved by adopting a system of reaping zones which showed better comparative yields each month of the cropping period. He also estimated that this policy change, depending on the utilization and availability of irrigation, could increase yields by between 12.5 and 16.5 percent.

A linear programming model was used by Tonsman (1974) to predict, for different periods, which fields should be harvested, and the amount and type of machinery that should be used at each location. This model included in the optimization process, such agricultural characteristics as seeding type and variety, soil preparation, irrigation regime, fertilization, climatic conditions, water availability, machine field capacities, transportation equipment and the factory's production programme, among others. Based on recommendations which resulted from this work, improvements of 14 percent and 30 percent in the ratios of sugar produced to cane milled and sugar produced to harvested area, respectively, were observed.

Hoekstra (1973, 1974, 1975) constructed three simulation models for a single cane harvesting and handling system in South Africa. His first model examined the effect of mill stoppages on transport units which off-loaded directly into the factory. The results indicated that the total number of transport unit hours lost over the cropping period, for mill stoppages ranging from less than 10 minutes to 5 hours, was negligible. In his second model, he examined mill yard operations. In this model, four vehicle types were processed through one of two unloading and each vehicle had to be weighed in and out. In general, the simulation results showed that improvement in the cane flow through the system could be achieved by improving the communications between the mill yard and the different suppliers, and by increasing the amount of cane delivered directly into the mill. In the third simulation model, the influence of mill operations on the delay time between cutting and milling was examined. In general, it was found that the delay between cutting and milling was dependent only on the respective timing of the cutting. Grinding over six days reduced both the mean and the spread of delay times. Hoekstra also indicated that the spread of delay times about the mean was not due to the irregular grinding of deliveries but rather to variances from a strict first-in first-out policy of milling cane deliveries.

Cochran and Whitney (1975) examined the effect of different numbers of transport units on field loader utilization. The overall results of their work were combined with a theoretical analysis adopted from the work of Melissa (1966) to develop a nomograph which permits graphical prediction of delivery rates for given values of transport unit capabilities, mean loading rate, total trip time and the number of transport units. A cost model was also developed to facilitate selection of the optimum number of transport units for any given system configuration. Loader transport system costs were broken down into three categories.

(1) Labour cost - defined by equation 11

(2) Equipment fixed cost - defined by equation 12

(3) Equipment operating costs - defined by equation 13

The total loader transport system cost (TC) is obtained by summing the three equations 11-13 to give equation 14. The equations are as follows:

$$\text{System labour cost} = Wlo + (Nt)(Wtr)/Del \quad \ldots\ldots\ldots\ldots \quad (11)$$

$$\text{System fixed cost} = Lfc + (Nco)(Cfc) + \sum_{i=1}^{to} Tfci/Thui)$$

$$(1/Del) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

$$\text{System operating cost} = Loc/R + (Coc + Nt/Nc \cdot Toc) \cdot (tp/(S)(Cc)) \quad (13)$$

$$\text{Total cost, } TC = 1/Del((Lfc + (Nco)(Cfc/Shu + \sum_{i=1}^{to} Tfci/Thui + Wlo + (Nt)(Wtr)) + (Loc/R + (Coc + Nc/Nc \cdot Toc \cdot tp/((S)(Cc)) \quad (14)$$

where

TC	= Total transport cost	\$/tonne
Lfc	= Loader fixed cost	\$/year
Cfc	= Cart fixed cost	\$/year
Tfci	= ith tractor fixed cost	\$/year
Thui	= ith tractor hours of use per year	hours/year
Shu	= Season hours of use	hours/year
Wlo	= Labour cost for loader operator	\$/hour
Wlr	= Labour cost for tractor operator	\$/hour
Loc	= Loader operating cost	\$/hour
Coc	= Cart operating cost	\$/hour
Toc	= Tractor operating cost	\$/hour
tp	= Round trip distance (field to mill)	kilometres
Nt	= Number of transport tractors in use	
Nc	= Number of carts in use	
R	= Loader rate for given conditions	tonnes/hour
S	= Average speed of transport units	kilometers/hour
Cc	= Cart capacity	tonnes
Del	= Transport system production rate to mill	tonnes/hour
Nco	= Number of carts owned	

Nto = Number of tractors owned and reserved for transport system use only during harvesting season

One of the more recent applications of simulation modelling to sugar cane handling was reported by Ogilvie et al. (1978). These researchers investigated the handling and transport of hand-cut whole stick sugar cane at the Frome Cooperative Farm in Jamaica. Two computer simulation models were constructed; one for the field operations and one for factory yard operations. They reported that the models developed permitted the testing of current and modified equipment arrangements and management policies, which in turn resulted in higher throughput and optimum use of transport and handling equipment. They also reported that the GASP IV simulation language used for constructing the models not only proved to be most adaptable to the system studied, but also provided the user with excellent intrinsic filing and report formatting routines and capabilities.

Loewer et al. (1979) developed a computer model to optimally select sets of equipment for 56 possible alternatives through the sugar cane harvesting network in Brazil, and to compute the labour requirements and fixed, variable, indirect and total costs. The results of the simulation indicated that transportation costs accounted for 60 percent of the total cost of harvesting sugar cane under Brazilian conditions. It was concluded, therefore, that modification of the transportation activity offered the greatest potential for reducing total harvesting and handling costs.

3.5. Computer Simulation Languages

In implementing a systems model on a computer, the user has the option of using a general purpose programming language or one of several special purpose simulation languages. General purpose programming languages that may be of interest to the simulation modeller are FORTRAN, ALGOL, BASIC, and PL/1. On account of their generality, these languages may be used to construct simulation models of any type of system. However, the modeller is required to develop his own input-output routines, set up his own time clock and switches within the model, and write his own special purpose routines such as normal pseudorandom number generators (Dent and Blackie, 1979). Modelling using these languages requires considerable programming ability and a reasonable knowledge of the computer and its associated systems (Manetsch and Park, 1980).

Special purpose simulation languages, on the other hand, have evolved in response to a need to reduce the programming skill and effort required to program and use computer simulation models (Krasnow and Merikallio, 1964). These languages contain specialised facilities, such as automatic time-keeping routines and sophisticated output formatting routines, which are convenient for modelling particular types of problems (Teichrow et al., 1966). Some of these languages are really supersets of general purpose languages (for example CSMP is a superset of FORTRAN) whereas others, such as GPSS, are self-contained (Tocher, 1965). In any case, most of these languages were originally developed to satisfy the requirements of specific problems and they, therefore, differ in the type and range of their possible applications. Manetsch and Park (1980) described a number of criteria by which simulation languages may be evaluated. These are as follows:

<u>Language type</u> - Simulation languages are classified as either 'discrete event' or 'continuous flow' or both of these. Discrete event languages are designed to simulate real world systems when a microscopic viewpoint, which considers individual objects or events as entities, is appropriate. In contrast, continuous flow languages are designed to simulate systems which are best characterized by aggregates or flows of discrete entities. Models of such systems are normally structured using differential and/or difference equations and continuous flow languages usually contain integration packages designed to efficiently obtain particular solutions for large sets of such equations.

<u>Universality</u> - This criterion describes the generality of a language with respect to the range of computers with which it is compatible. Some languages are very machine dependent and are useable only on limited computer makes, models and sizes.

<u>Higher Order Modularity</u> - Situations are sometimes encountered in which a complex sub-system structure occurs repeatedly in the structure of the larger total system (for example, similar machines in a production process). In such cases, it is often possible in simulation to design one basic model 'higher order building block' which can be used repeatedly in the overall model (with different inputs and structural parameter values where necessary) to model the replicated sub-system whenever it occurs. This capability of a language is termed 'higher order modularity' since it involves modularity vis-a-vis a model component constructed from more basic components.

Programmability - This criterion relates to the programming effort required to program and operate models in a given language. The concept is somewhat arbitrary since it is often highly dependent upon the particular problem at hand. Nevertheless, for some types of problems, some languages are easier to work with than others.

Optimization Capability - Some simulation languages offer the facility of running simulation models linked with optimization routines (such as Complex or Powell's routines) which use search or other techniques to optimize the performance of the model with respect to some criterion.

Output Formats - Most special purpose simulation languages include 'canned' output formats which provide selected model outputs in tabular, graphical (versus time), histogram or other forms. Such facilities can significantly reduce model programming requirements.

The following is a tabulated comparison of a number of contemporary simulation languages. The table was originally compiled by Manetsch and Park (1979) for six languages, based on the six criteria described above, but has been extended by the author to include an additional simulation language 'GASP IV' and an additional descriptive criterion 'Error Diagnostics'.

Table 3.1 Comparison of some contemporary simulation languages

Language	Discrete Event	Continuous Flow	Universality	High Order Modularity	Programmability	Optimization Capability	Output Formats	Error Diagnostics
CSMP		X	Limited number of large computers	Yes	Good	Yes	Good	Good
DYNAMO		X	Moderate for large scale machines	Yes	Good	No	Good	Good
FORDYN		X	Excellent for most machines	Yes	Fair	Yes	Fair	Fair
FORTRAN	X	X	Excellent for most machines	Yes	Poor	Yes	Poor	Poor
GASP II	X		Excellent for most machines	No	Fair	Yes	Good	Good
GASP IV	X	X	Excellent for most machines	Yes	Fair	Yes	Very Good	Good
GPSS	X		Limited number of large machines	No	Good	No	Good	Good
SIMSCRIPT	X	X	Good for large machines only	?	Fair	Yes	Good	Fair
FORTRAN & FORDYN & GASP II	X	X	Excellent for	Yes	Fair	Yes	Fair	Fair to Good

CHAPTER 4

METHODOLOGY AND MODEL DEVELOPMENT

4.1. Introduction

Most agricultural crop harvesting and transportation systems can be represented by some form of closed circuit queuing system as shown in Figure 3.1. Essentially, such a system consists of cutting the crop and loading it into transport units which are then taken to a processing, storage or other facility where unloading takes place (often after the loaded transport units are weighed). Empty transport units are subsequently returned to the field. Since a service facility (e.g., harvester, scale or unloader) is not always free on arrival of a transport unit, service queues often build up within the system.

The calculation of the capacity of cyclic queuing systems can be rather complex, especially in an agricultural context, due to the wide variability of operating conditions that may prevail. One relatively simple approach to finding approximate solutions for such systems is through the use of computer simulation programs. In such programs, the variability of operating conditions can be handled by using appropriate statistical distributions to represent the operating times of the different pieces of equipment involved in the system (Dumont and Boyce, 1972). This chapter describes the simulation methodology used to study mechanical harvesting and handling of sugar cane under Barbadian conditions.

4.2. Model Development Approach

There are two distinct systems of mechanical harvesting of sugar cane in use in Barbados: chopper harvesting and whole-stick harvesting. In the chopper harvesting system, the cane harvested by a combine is delivered directly into a wagon pulled alongside the harvester by a field tractor. When a wagon is filled, it is moved from under the delivery chute of the harvester and an empty wagon is drawn up in its place in such a manner as to ensure continuous harvester operation. In the case of the whole-stick system, the cane is cut by a mechanical cutter and then loaded by a mechanical grab loader (in a separate operation) into a transport trailer pulled alongside the loader in the field. In either system, filled transport units are deposited in a queue at the edge of the field and, when a complement of two full wagons or trailers and a road tractor becomes available, a trip is dispatched to the factory. The actual flow of individual operations performed on each transport unit during the entire harvesting and handling process is shown in Figure 4.1. Operations above the 'broken line' on the Figure are associated with the field subsystem, while those below the line are involved in the factory subsystem.

For the purposes of this study, the overall cane harvesting and handling system was broken down into two subsystems: a field subsystem and a factory subsystem -- a division not at all unrealistic since in Barbados, the cane production and processing sectors are separately owned and managed entities (see Chapter 2). Each subsystem was then decomposed into its specific activities, and events identified such that each activity was bounded by a pair of sequential time events, one

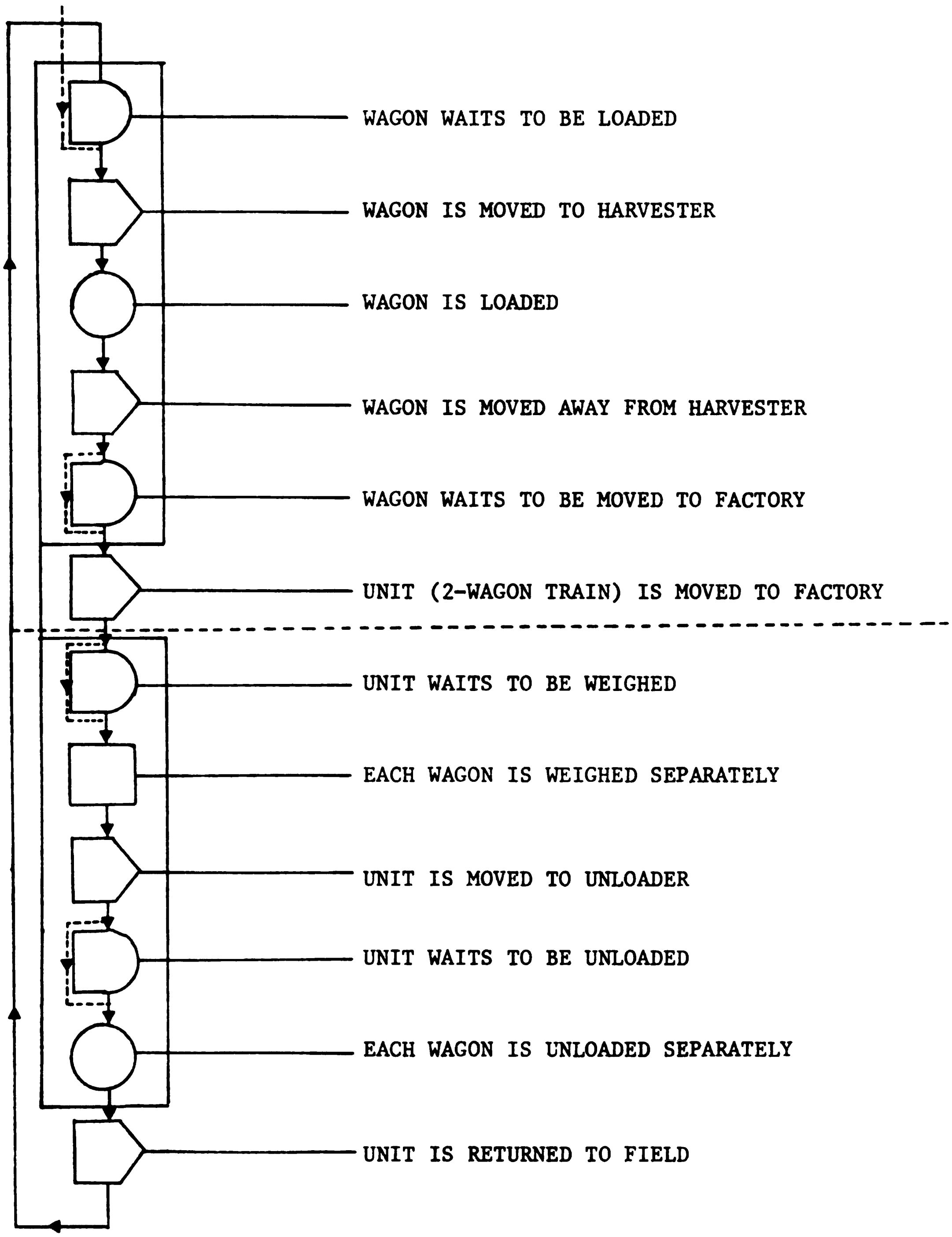


Figure 4.1. Flow process chart of operations performed on each transport unit

signalling its start and the other signalling its end. The time to perform a given activity was calculated by finding the lapse time between the relevant pair of sequential events.

Two computer simulation models were then developed: a field operations model (FIELDOP) to simulate the activities involved in the field subsystem; and a factory yard operations model (FACYARD) to simulate the activities involved in the factory subsystem. Based on a review of the literature on simulation models and computer simulation languages, the GASP IV simulation language was selected for constructing both models. Details of this language are presented in the following section.

4.2.1. An Overview of the GASP IV Simulation Language (Source: Pritsker, 1974)

Simulation is a problem solving procedure for defining and analysing a model of a system. Digital computer simulation, as defined by Pritsker (1974), is "the establishment of a mathematical-logical model of a system and the experimental manipulation of it on a digital computer."

Simulation languages typically provide the structure and the terminology to facilitate the building of simulations and relieve the user of a considerable amount of personal programming effort. GASP IV is such a language. It helps the user to build computer simulation programs that can be both the model of the system and the vehicle for analysing the system.

The philosophical basis for the design of GASP IV is the concept of modelling a system in two dimensions: the time dimension and the state-space dimension. Fundamental to building a GASP IV simulation model is the decomposition of time and state space into manageable elements. The decomposition in the time dimension requires the user to define events and potential system changes generated by these events, to specify the causal mechanisms by which events can occur, and to define the mathematical-logical relations that transpire when an event occurs.

In the state-space dimension, GASP IV presumes that a system model can be decomposed into its entities, which are described by attributes. Attributes may be discrete or continuous. A discrete attribute is one whose value remains constant between event times, while a continuous attribute is one whose value may change between event times according to a prescribed code of dynamic system behaviour. Continuous attributes are referred to as "state variables". In essence then, GASP IV provides a formalized view of the world which specifies that the status of a system be described in terms of a set of entities and their associated attributes and state variables.

In GASP IV, an event occurs at any point in time beyond which the status of a system cannot be projected with certainty. Events are described in terms of the mechanism by which they are scheduled. Those that occur at a specified projected point in time are referred to as "time events", while those that occur when the system reaches a particular state are called "state events".

The behavior of a system model is simulated by computing the values of the state variables at small time steps and the values of attributes at event times. GASP IV automatically decomposes the time axis into points at which events occur, based on the equation form of the state variables, the time of the next event and accuracy and output requirements. The user is, therefore, relieved of the task of sequencing events.

When an event occurs, it can change the status of the system in three ways: by altering the values of the state variables or the attributes of the entities; by altering relationships that exist among entities or state variables; and/or by changing the number of entities present. Methods are available in GASP IV for accomplishing each type of change.

At each time step, the state variables are evaluated to determine if the conditions prescribing a state event have occurred. If a state event was passed, the step size was too large and is reduced. If a state event occurs, the model status is updated according to the user's state event subroutine. Step size is automatically set so that no time event will occur within a step, by setting the step size so that the time event ends the step.

Since time events are scheduled happenings, certain attributes are associated with them. At the minimum, a time event must have attributes that define its time of occurrence and its type. If the time event is associated with an entity, then either the attributes of that entity must be associated with it or the event must be able to refer to the attributes of the entity. For example, if there is an end-of-service event for an item, the attributes for that item must, in some way, be associated with the event. A filing system is provided for storing entities and their associated attributes. System monitoring procedures, which can be pre-scheduled or called as required, are also provided.

GASP IV is designed to provide eight specific functional capabilities:

(1) Event control

(2) State variable updating using integration, if necessary

(3) System state initialization

(4) Program monitoring and event reporting

(5) Information storage and retrieval

(6) System performance data collection

(7) Statistical computations and report generation

(8) Random deviate generation.

The first four of these capabilities are primary functions which constitute the basic modes of the language as shown in Figure 4.2. The remaining four are support oriented.

GASP IV has two forms of program control. One, the executive function, directs the system program into its various modes: initialization, state variable updating, monitoring, etc. The other, the event selection function, operates within the simulation model and sequences the execution of event routines. The modular structure of GASP IV allows event logic to be changed relatively simply to investigate the effect of changes in a system on selected measures of system performance, since each event is, in fact, a separate subprogram. A data pool allows changes made in data inputs to be communicated throughout an entire simulation model. The preparation of reports summarizing the results of simulation runs is simplified by utilizing standard report programs that obtain their information from the common data pool. Model debugging is also facilitated by the provision of access points at which program results can be sampled without interfering with the logic of particular events.

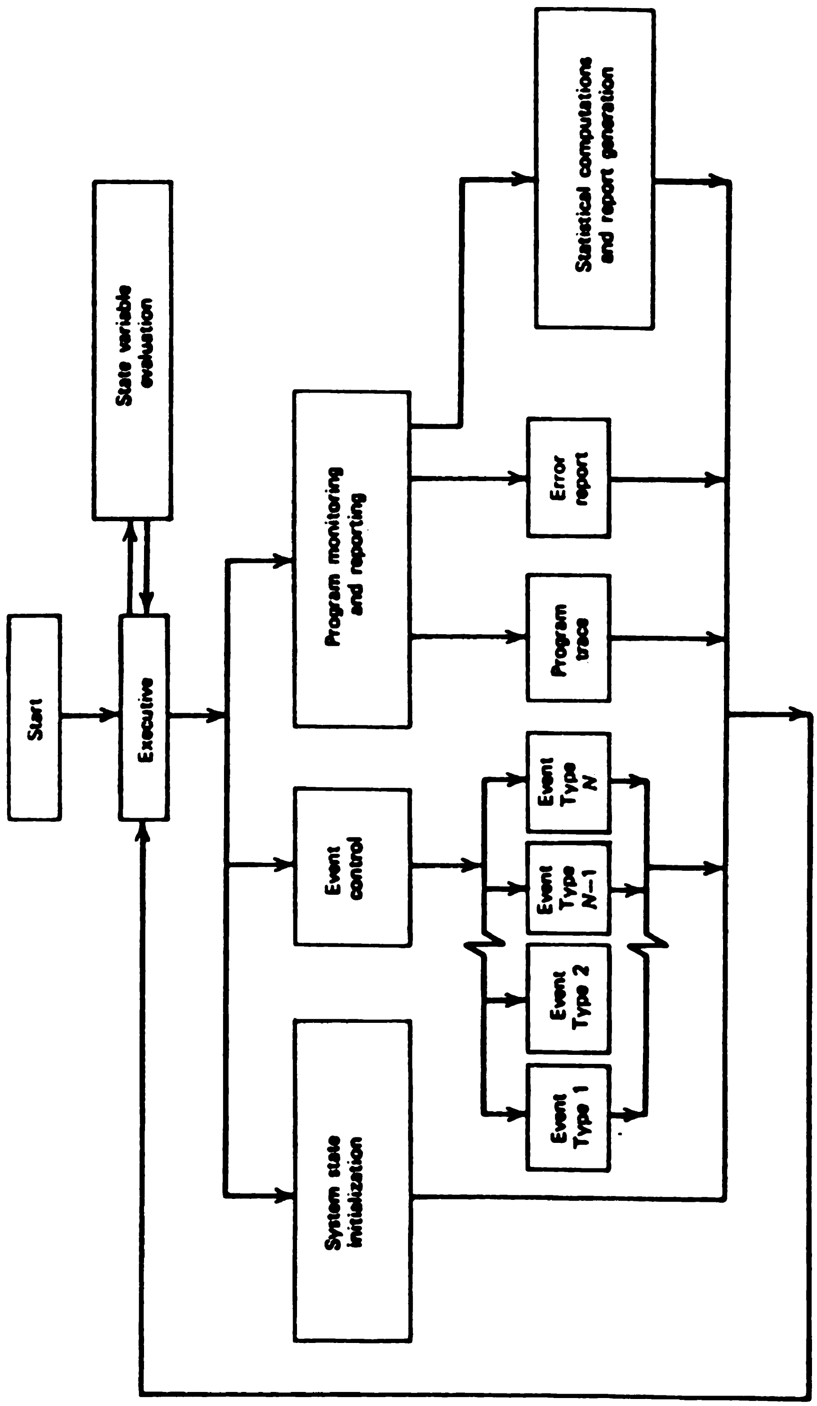


Figure 4.2. Basic modes of GASP IV control.

In summary, GASP IV has five distinct features that make it particularly attractive as a simulation language:

(1) The language is FORTRAN based and requires no separate compiling system. It is easily maintained and can be implemented on new computing systems and on the computing systems of different manufacturers.

(2) GASP IV is modular and can be made to fit on all machines that have a FORTRAN IV compiler.

(3) GASP IV is easy to learn since the host programming language is usually known and only the simulation concepts need to be mastered. The implementation of these concepts is apparent to the user.

(4) GASP IV can be used for discrete, continuous, and combined simulation modelling, and is the only well-documented simulation language with this capability (see Table 3.1)

(5) GASP IV can be easily modified and extended to meet the needs of particular applications.

A functional flowchart of a GASP IV program is presented in Figure 4.3.

4.3 The Field Operations

4.3.1. Objectives

The main objective of simulating the field operations was to identify changes in the cane harvesting and transportation procedures that could lead to increased efficiency of utilization of the expensive chopper

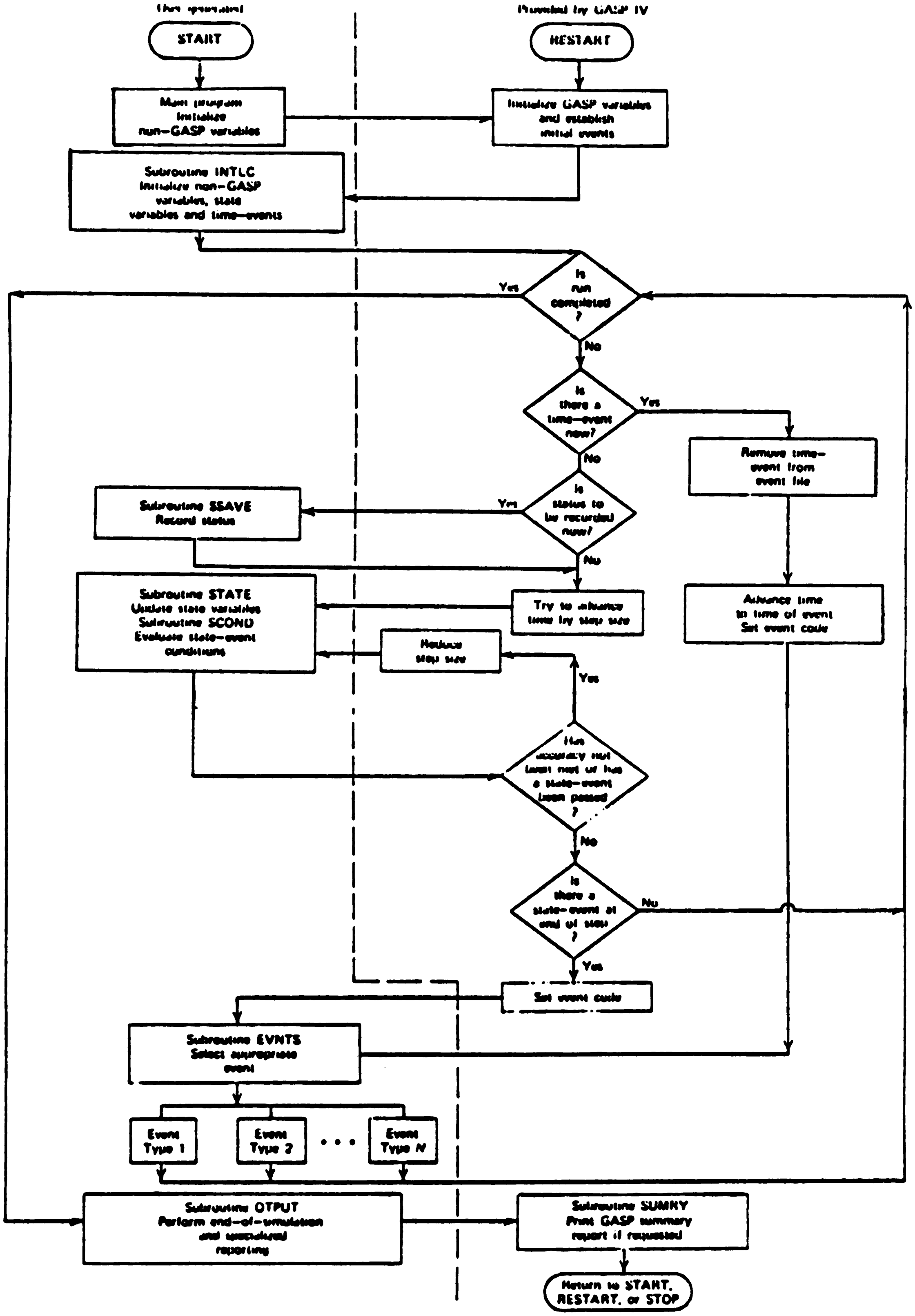


Figure 4.3. Functional flowchart of a GASP IV program.

combine harvesters and their associated equipment. Specific objectives were as follows:

1. Determination of the current levels of utilization of the chopper harvesters and of the cane transportation equipment within the field subsystem.
2. Construction of a computer simulation model to accurately reflect the operational characteristics of the field subsystem.
3. Use of this model to determine the effect on potential subsystem output of variations in the characteristics, specifications and combinations of different subsystem components.
4. Use of the simulation model to test recommendations which may be implemented to improve and/or optimize the overall performance of the field harvesting and cane transport operations.

4.3.2. Activities and Events

The principal activities involved in the field subsystem are the loading of empty cane transport vehicles and the dispatch of full transport units to the factory for processing (Figure 4.4). Inevitably, road tractors are not always available whenever a complement of two full wagons is ready for transportation to the factory, neither are harvesters always free when empty transport wagons return to the field. Queues of full and empty wagons, therefore, form an integral part of the field subsystem.

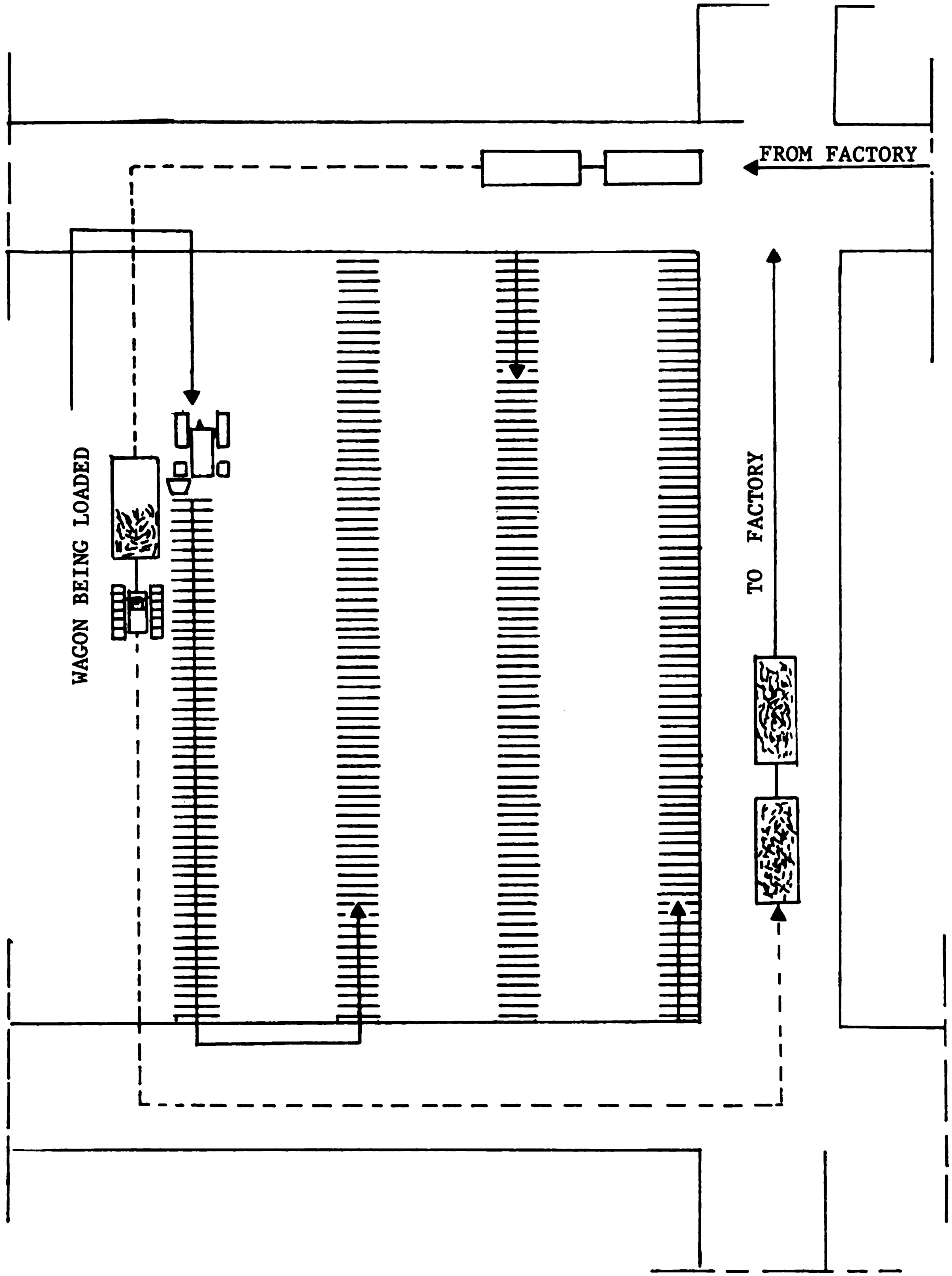


Figure 4.4. Activities involved in the field subsystem

The specific sequential time events identified and monitored for the field operations model are detailed in Table 4.1 and the sets of activity times derived from these time events are as follows:

1. TTHT: - travel time of field tractor and empty wagon combination to harvester for loading (STLD - STHK).
2. LTPW: - loading time per wagon, including turning time at the end of each row when applicable (ENDLD - STLD).
3. TTFQ: - travel time of a field tractor plus a loaded wagon to the queue of full wagons (ENDUH - ENDLD).
4. HIT: - harvester idle time due to unavailability of empty wagons at the field ($STLD_{n+1}$ - $ENDLD_n$).
5. TTTF: - travel time of a road tractor and its complement of two full wagons from the field to the factory (ARFCT - DPFLD).
6. ZATU: - inter-arrival time of cane transport units (a unit being 1 road tractor plus 2 wagons) at the factory ($ARFCT_{n+1}$ - $ARFCT_n$).
7. RTFCT: - residence time for a transport unit at the factory (DPFCT - ARFCT).
8. TTFLD: - travel time of road tractor plus two empty wagons from factory back to field (ARFLD - DPFCT).

4.4. The Factory Yard Operations

4.4.1. Objectives

The main objective of simulating the factory yard operations was to identify changes in the layout and organization of the yard which

Table 4.1. Events monitored for the field operations.

Event	Event Code	Definition
Start hook	STHK	Time at which a field tractor stops in front of an empty wagon in preparation for hitching.
Start load	STLD	Time at which the first cane hits the bottom of the wagon.
End load	ENDLD	Time at which the rear end of the loaded wagon passes the front end of the harvester on its way to the queue of full wagons.
End unhook	ENDUH	Time at which a field tractor starts moving, having deposited a loaded wagon in the queue of full wagons.
Depart field	DPFLD	Time at which a road tractor plus its complement of two full wagons starts moving enroute to the factory.
Arrive factory	ARFCT	Time at which the front wheels of the road tractor cross the entrance to the factory.
Depart factory	DPFCT	Time at which a road tractor plus its complement of two empty wagons or trailers first start to move enroute back to the field, the cane having been unloaded.
Arrive field	ARFLD	Time at which a road tractor and its complement of two empty wagons stop in the queue of empty wagons at the field, having returned from the factory.

could lead to improved operating efficiency, before committing large sums to major physical changes in yard configuration. Specific objectives were as follows:

1. Determination of the current levels and rates of utilization of existing equipment and the overall output of the factory cane handling system.
2. Construction of a computer simulation model to accurately represent the current configuration of a given factory yard.
3. Use of this simulation model to investigate the effects of changing the values of certain model parameters and variables so as to achieve varying operational characteristics of the factory yard processes.
4. Minimization or reduction of the residence time of cane transport equipment in the factory yard, since this implies more efficient use of both the cane harvesters and the transport vehicles.

4.4.2. Activities and Events

The principal activities involved in the factory yard process are weighing and unloading of the cane transport vehicles. Since, however, the service facilities (scales and unloaders) are not always free when a transport unit arrives at the service area, two additional activities "waiting in the queue to the scale" and "waiting in the queue to the unloader" were also considered.

The sequential time events identified and monitored for the factory yard operations are listed in Table 4.2 and the activity times derived

Table 4.2. Events monitored for the factory yard activities

Event	Event Code	Definition
Arrive factory	ARFCT	Time at which the front wheels of the road tractor cross the entrance to the factory.
Start weigh	STWGH	Time at which the front wheels of the road tractor first make contact with the weigh scale platform.
End weigh	ENDWGH	Time at which the rear wheels of the second wagon or trailer (in a train) leave the weigh scale platform.
Start unload	STULD	Time at which the chains of the unloading crane or hoist first make contact with a full wagon or trailer.
End unload	ENDULD	Time at which a road tractor and its complement of two empty trailers or wagons first starts to move en route from the factory after the cane has been unloaded.

from these events are defined below:

1. Weigh Q-time: - time road tractor and its complement of two full wagons or trailers spend in the queue waiting to be weighed (STWGH - ARFCT).
2. Weigh time: - time to weigh complement of two wagons or trailers (ENDWGH - STWGH).
3. Unload Q-time: - time road tractor and its complement of two full wagons or trailers spend in the queue waiting to be unloaded (STULD - ENDWGH).
4. Unload time: - time to unload complement of two wagons or trailers (ENDULD - STULD).
5. Factory Residence time: - total time road haulage tractor and its complement of two wagons or trailers are retained at the factory yard (ENDULD - ARFCT).

4.5. Data Acquisition and Analysis

The main data required for this study were duration times of the various activities involved in the Field and Factory yard operations. As stated in Section 4.2, these times were obtained by monitoring the occurrence times of sequential events and then calculating the lapse times between appropriate pairs of events. The event times monitored for the field and factory yard systems have already been presented in Tables 4.1 and 4.2, respectively.

4.5.1. Data Acquisition

The data collection for this study was undertaken during the period February 24 to April 10 of the 1982 cane harvesting season in Barbados.

For this exercise, five monitors were employed, to of whom were assigned to the field operations and three to the factory yard operations.

In the case of the field operations, one monitor was responsible for recording the event times associated with the loading process involving interaction of the combine harvester, the field tractors and the transport wagons. Event times associated with the arrival of empty transport units at the field and the departure of full transport units to the factory were recorded by the other monitor.

In the case of the factory yard operations, one monitor recorded transport unit arrival times at the factory while a second monitor recorded event times associated with the weighing activity for all transport units as well as those associated with the unloading activities for chopped-cane units. The responsibility of the third monitor was to record event times associated with the unloading of whole-cane transport units.

All persons selected as monitors were required to study an instruction manual which explained the data collection process and described how to identify the precise times at which the various events occurred (see Appendix I). In addition, prior to the commencement of the actual data collection, the monitors were taken into the field and each was shown exactly how to record his own data as well as the data for which each of his co-workers was responsible. This precautionary measure was taken to ensure that monitors could be readily inter-changed as and when the need arose.

Each monitor was equipped with a clip-board, an adequate number of data recording forms, scoring pencils and pens and a digital quartz watch with a continuous, 6-digit time display. In order to synchronize events occurring at various points in the system, all watches used were adjusted on the first day so that they all read the same time and kept synchronized throughout the study.

Data recording consisted of entering the event times and the identity of the field tractors or road tractors (registration numbers) in the appropriate columns on the forms. The comment number column was used to identify activity times during which unusual events occurred. A comment number consisted of two numbers; a row (observation) number and a column (event) number which together indicated the exact event time entry to which the comment referred. The actual comments were written in the "comments" section provided at the bottom of the data recording form. Samples of some actual data are given in Appendix I.

4.5.2. Data Analysis

In order to model the specific events using the intrinsic distribution functions of the GASP IV simulation language, it was necessary to select appropriate statistical distributions to represent the various activity times and then determine suitable parameters for these distributions. Based on the literature review presented in Chapter 3, activity times for the loading, weighing and unloading processes, and waiting times in the queue to the various servers can all be represented by either the Erlang or the Gamma distribution. Since the latter is a more general form of the former (which itself is a more general form of the Exponential distribution) it was decided to use the Gamma distribution to determine the appropriate parameters for the distributions of the activity times mentioned above.

Two forms of the Gamma distribution exist: a 2-parameter version which assumes that the minimum value for the dependent variable is always zero and a 3-parameter version which allows the dependent variable to take on minimum values greater than zero (Figure 4.5). Since, for this study, the minimum values of service or activity times are always positive, the 3-parameter Gamma was the version fitted to the data in all cases.

4.5.3. The Data Analysis Program

Most of the program used was taken from a program originally developed by Dumont (1972). The original program accepted activity or service times which it processed and analysed as statistical distributions, using the maximum likelihood method to fit the distribution. It was later modified by Ogilvie et al. (1978) to provide for input data manipulation into a form suitable for curve fitting analysis. Minor improvements in the computer code and general program flow have been made by the author.

The general flow through DATANAL is shown in Figure 4.6. The program accepts data in sequential event time form just as it is recorded in the field. Subroutine DACON converts the 6-digit event times from the 'hour, minute and second' mode to a single decimal number, single unit mode. In subroutine COLDIF successive event times are subtracted from preceding event times so as to produce columns of single unit decimal service times. These columns of service times are then sorted in ascending order by the main program and used as input to subroutine SIMPLE which determines the values of the three parameters of the GAMMA distribution for each column in turn. Output from the program

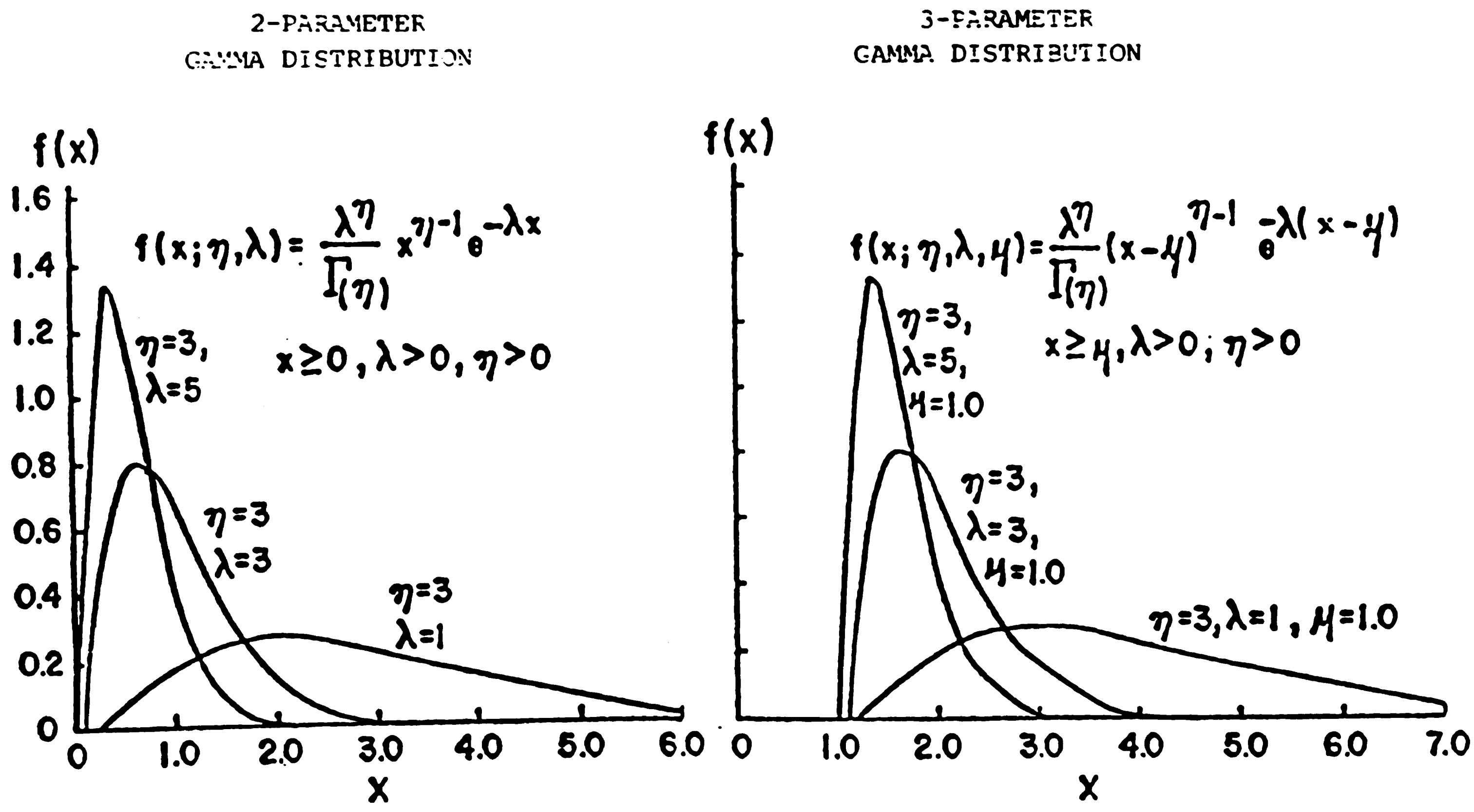


Figure 4.5. The 2- and 3- parameter forms of the Gamma distribution.

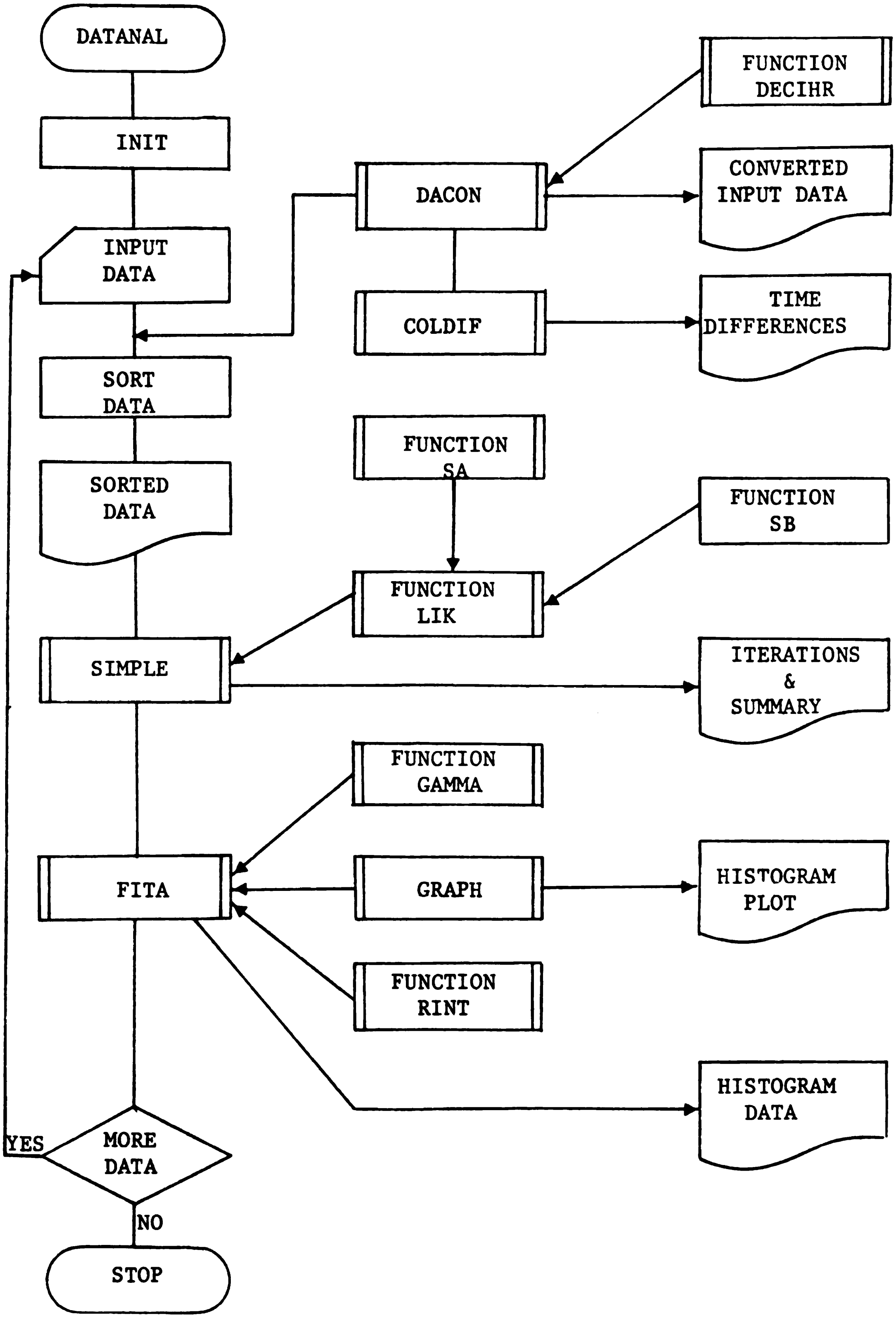


Figure 4.6. Flowchart through Data Analysis Program (DATANAL)

includes: a list of input event data converted to single unit data, a list of activity or service times, histograms of the distribution for each activity time and parameter values calculated for each distribution. The computer listing of program DATANAL is given in Appendix II.

CHAPTER 5

FIELD AND FACTORY YARD COMPUTER SIMULATION MODELS

5.1. Introduction

A system may be defined as a set of inter-connected elements or components which interact, under a prescribed set of conditions, to achieve a specific goal or set of goals (Naylor et al., 1968). In general systems terminology, a number of different systems components have been identified (Manetsch and Park, 1980). These are:

1. Exogenous or environmental variables: these are input variables determined by factors completely independent of or external to the system, and which together constitute the system environment.
2. Entities: these are objects within the boundary of the system.
3. Endogenous or dependent variables: these are internal or output variables of a system which are generated or caused by system inputs and/or interaction or other endogenous variables.
4. System boundary: this is an imaginary line which separates endogenous system components from the exogenous variables or the system environment.
5. System output variables: these are variables caused by a given system and are used either as inputs to another

system or as measures of performance of the given system.

6. Controllable input variables: these are input factors which can be used as a means of overtly altering system behaviour, usually in a beneficial manner. They are also known as management or decision variables.

The set of interactions of elements and related variables that intervene in the causal chain linking system outputs to system inputs is referred to as the systems structure. Causal loop diagrams, in which the system elements and the variables that interact among them are represented in two dimensions, are often used to illustrate system structure.

5.2. Field Operations Simulation Model

5.2.1. The System Environment

In the case of the field operations model (FIELDOP), the system environment consists of the following exogenous variables:

- Cane variety (its suitability to mechanical harvesting)
- The conditions of the field
- The daily quota of cane fixed by the factory
- The factory yard conditions (degree of congestion)
- The road conditions (traffic congestion)
- The climatic conditions (particularly rainfall)
- The operational policies of management
- The travel distance between the field and the factory.

The first five factors may affect the output of the harvester directly, while the remaining three would tend to affect the turn-around time (total round trip time) of cane transport units (see Figure 5.1). For purposes of model simplification, however, a number of assumptions were made about these factors:

1. The travel distances between fields and factories are known.
2. Variations in field, factory yard and road conditions can be handled by using appropriate statistical distributions of the work times for the various operations performed at these locations.
3. Since the daily quota of cane is established for six consecutive days of a week at the beginning of the week, over-supply on one day is deducted from the next day and under-supply is added.
4. The factory yard operations (weighing and unloading) can be represented as a single server operation for the field operations model, since total round-trip time is the time variables of interest here.
5. The field system operates from 7:00 a.m. to 7:00 p.m., six days a week with a break of one hour per day for lunch. Further, based on short-term observation, approximately one hour is utilized per day for repairs and general maintenance. Effectively, then, 10 hours (two 5-hour shifts) are available for work per day.
6. All harvesters, field tractors, road tractors and wagons in one location are identical and their work times can,

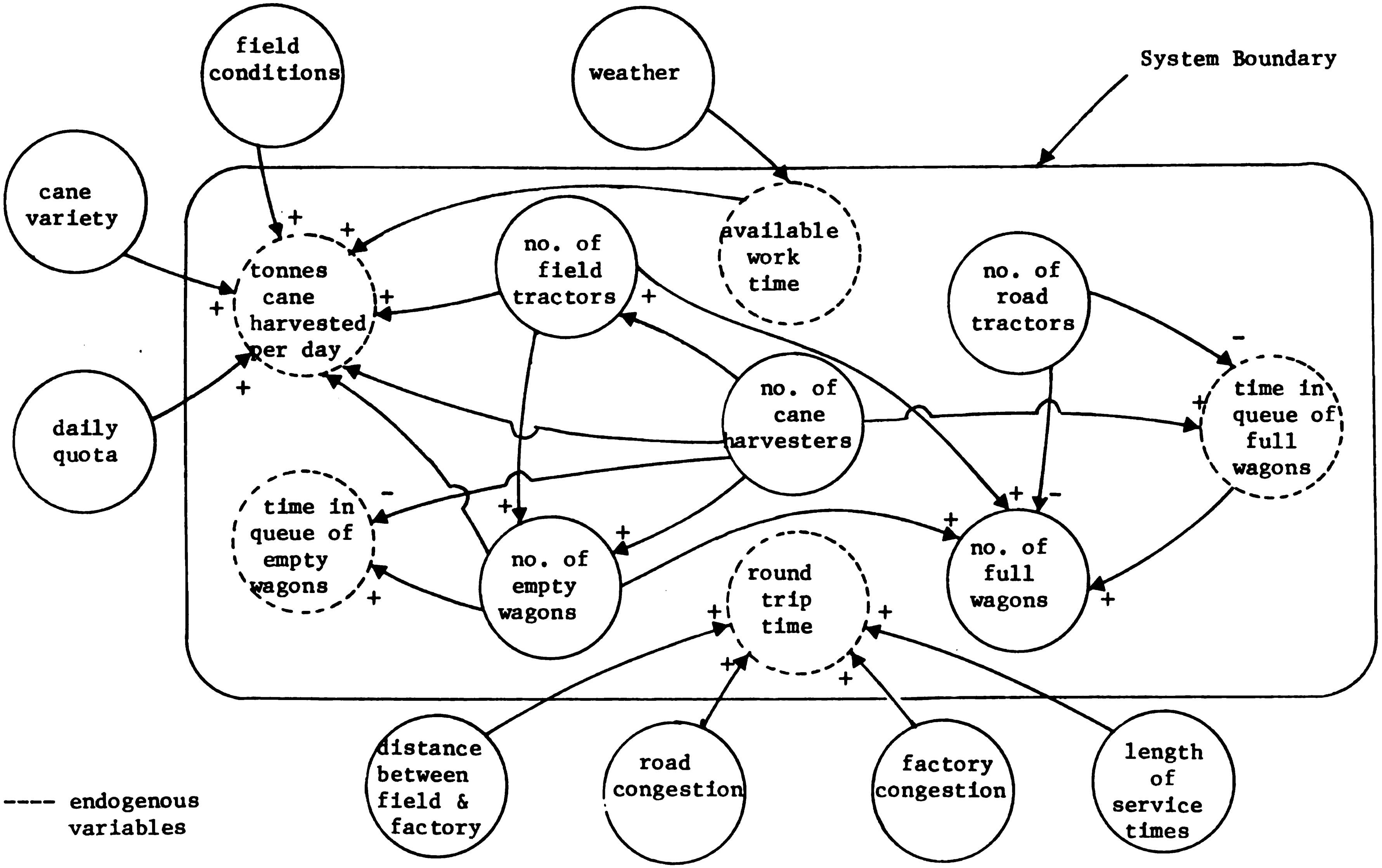


Figure 5.1. Causal loop diagram for the field system

therefore, be represnted by the same probability distributions.

7. A transport unit always consists of a road haulage tractor and a complement of two wagons.
8. Delays in field operation due to rainfall are infrequent in occurrence and negligible in duration.
9. Transport units and individual wagons are treated on a first-come, first-served basis throughout the system.
10. Agronomic practice dictates that, for a given field, only one cane variety is used.

On the basis of the above assumptions, the daily cane quota, the transport unit capacity, the length of a shift, the length of the break between shifts, and the operational policies of management are all considered to be constants in the system model.

5.2.2. Entities

The entities considered for the model are:

1. The mechanical (chopper) harvesters
2. The field tractors
3. The cane transport wagons
4. The road tractors

The operating personnel associated with the equipment (e.g., tractor operators, the harvester operator) are considered to be integral parts of the component equipment and do not affect the system as individuals. They are, therefore, not treated as separate entities in the model.

5.2.3. Endogenous Variables

The endogenous variables generated within the system boundary are as follows:

1. Time in the queue of empty wagons
2. Time in the queue of full wagons
3. Time to complete a round-trip
4. Tonnes of cane harvested per day
5. Available work time.

5.2.4. Output Variables

The output variables of interest for the field subsystem are:

1. The average total round-trip time
2. The average time an empty wagon waits at the field to be loaded
3. The average time a full wagon waits at the field to be transported to the factory
4. The utilization of the harvester
5. The utilization of a field tractor
6. The utilization of a road tractor
7. The number of trips completed per shift
8. The number of trips in transit at the end of a shift
9. The number of full wagons in the field
10. The total tonnes of cane delivered to the factory from the field subsystem.

5.3. Field Operations Simulation Program (FIELDOP)

As previously stated, in GASP IV each entity has one or more attributes associated with it. The entities and their associated attributes for the FIELDOP program are listed in Table 5.1. Nine files are used in the program for storing information on entities and combinations of entities at different points in time during the simulation. These files, along with the entities stored in each and the attributes used to rank entries in files, are shown in Table 5.2. Throughout the simulation, the identity of each piece of equipment is maintained by assigning it to the appropriate file. For example, if at the end of a shift, a field tractor and empty wagon combination remains in the field, the combination is dissembled and the field tractor put in the file for field tractors (File 5) while the empty wagon is placed in the file for empty wagons (File 2).

5.3.1. General Flow Through Program FIELDOP

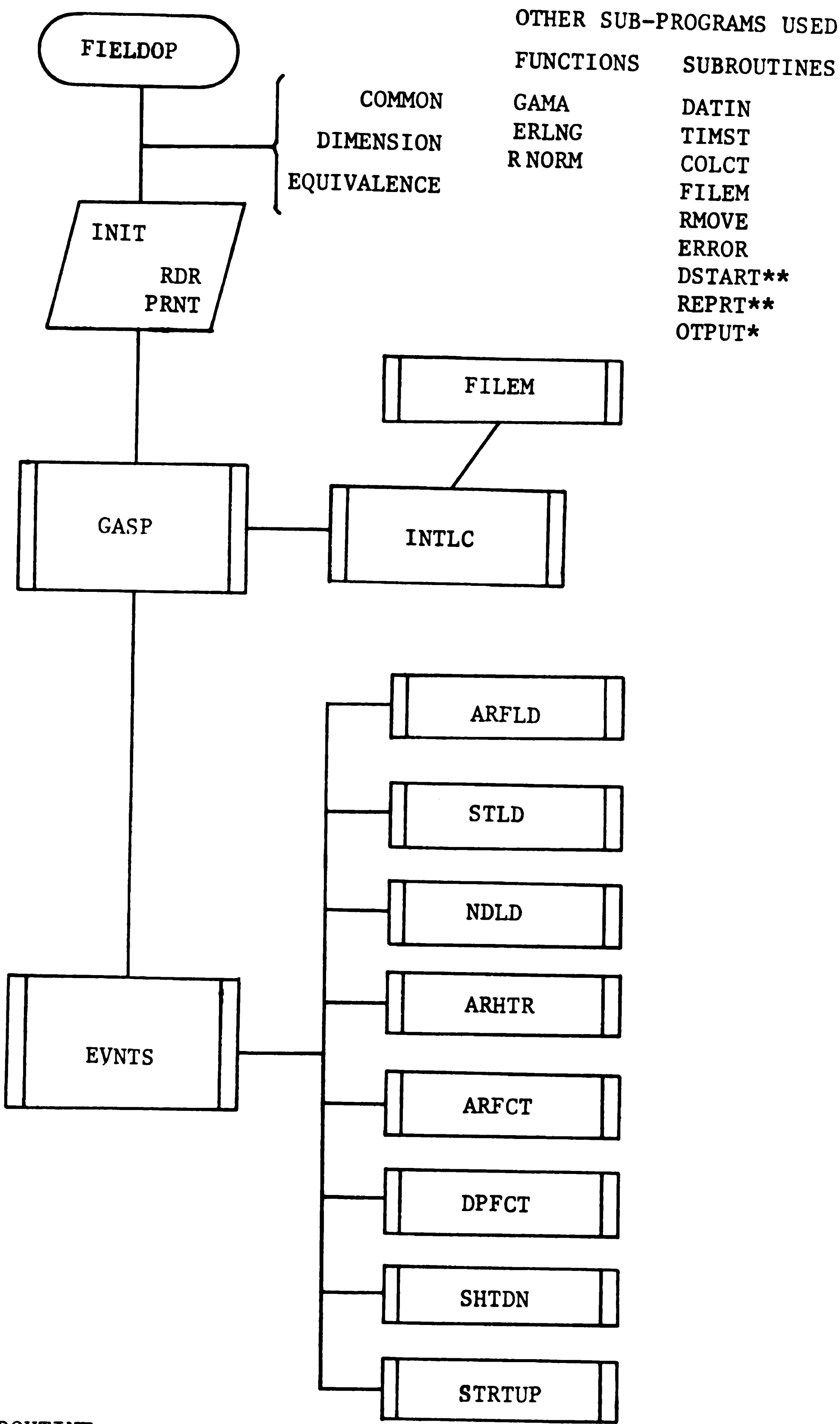
The general flowchart for program FIELDOP is presented in Figure 5.2. The main program assigns appropriate values to the card reader and printer units, reads in the initial values for non-GASP (user-generated) variables (Table 5.3), prints out a list of these variables, and initializes the GASP IV variables declared in the Dimension, Common and Equivalence statements before making a call to the GASP IV executive subroutine, GASP. The GASP IV subroutines DATIN and INTLC (user-written) are then called from subroutine GASP. DATIN enters input data read in by the main program and subroutine INTLC initializes the start, end, and operating work times, daily cane delivery quotas, report arrays and

Table 5.1. Entities and their associated attributes (FIELDOP)

Attribute		Entity			
Number	Description	Harvester	Field tractor	Wagon	Road tractor
1	Event time	X	X	X	X
2	Event code	X	X	X	X
3	Time of arrival in queue of empty wagon			X	
4	Time of arrival in queue of full wagons			X	
5	Time of departure from field			X	X
6	Time of arrival of a transport unit at factory			X	X
7	Time of departure of a transport unit from factory			X	X
8	Harvester number	X			
9	Field tractor number		X		
10	Road tractor number				X
11	Number of full wagons for one trip to factory			X	
12	Trip completion indicator			X	X
13	Identification of field location (i.e., NEST)	X	X	X	X
14	Time of entry into file 8		X	X	

Table 5.2. Files used in model FIELDOP

File no. (I)	Entries	KKRNK (I)	IINN (I)
1	Future events	1	3
2	Queue of empty wagons at field	3	3
3	Queue of full wagons at field	4	3
4	Queue of road tractors	13	3
5	Queue of field tractors	13	3
6	Harvesters	13	3
7	Information on road tractors processed at the factory	6	1
8	Field tractors and empty wagons coordinates waiting to be loaded	14	1
9	Transport units in transit at end of the morning shift	-	-



** USER SUBROUTINE
 * GASP IV SUBROUTINE (USER WRITTEN)

Figure 5.2. Flowchart through FIELDOP

Table 5.3. NON-GASP user input variables used in FIELDOP

Symbol	Definition
ISC	System condition: ISC = 1: simulate ISC = 0: end of simulation
NWG	Number of wagons
NHT	Number of harvesters
NFT	Number of field tractors
NRT	Number of road tractors
NEST	Identifies estate simulated
QUOTA	Estate delivery quota of cane for one day
CAP	Amount of cane delivered by a transport unit per trip (tonnes)
STM	Time of starting field operations on first day
ENT	Time of ending field operations on a work day
AMOUNT	Amount of quota remaining
DWN	Status of system: DWN = 0: system operational DWN = 1: system down
BREAK	One hour lunch break for which harvesting stops between shifts

equipment combinations, and establishes performance criteria for the simulation. A successful return to the executive routine GASP from DATIN is indicated by a print-out of the initial values established for GASP IV variables. The executive routine GASP then calls subroutine EVNTS (IX) which passes control to individual user-written event subroutines ARFLD, STLD, NDLD, ARHTR, ARFCT, DPFCT, SHTDN and STRTUP, in accordance with the value of the argument IX.

Subroutine ARFLD (Figure 5.3) is called when a transport unit, consisting of 2 wagons and a road tractor, arrives at the field, having delivered a load of cane to the factory. The road tractor is placed in File 4 and the empty wagons in File 2. The amount of the day's quota remaining is then calculated, as well as the round-trip time for the delivery. If the quota is satisfied, a shut-down event is scheduled and the road tractor is set idle. If not, the status of the harvesters is checked and a start of loading event is scheduled for each available harvester. If there is a complement of full wagons at the field, it is combined with the road tractor and a trip is dispatched to the factory. Otherwise, the road tractor is set idle.

Subroutine STLD (Figure 5.4) handled the start of a loading event. The harvester is combined with a field tractor and empty wagon combination and set busy. The end of loading is then predicted by generating a deviate from the Gamma distribution of loading time using parameter set #1 (see Tables 5.4 and 5.5).

Subroutine NDLD (Figure 5.5) simulates the activities in the field at the end of loading. The wagon just loaded is placed in the queue of full wagons (File 3) and the field tractor in File 5 (see Table 5.2).

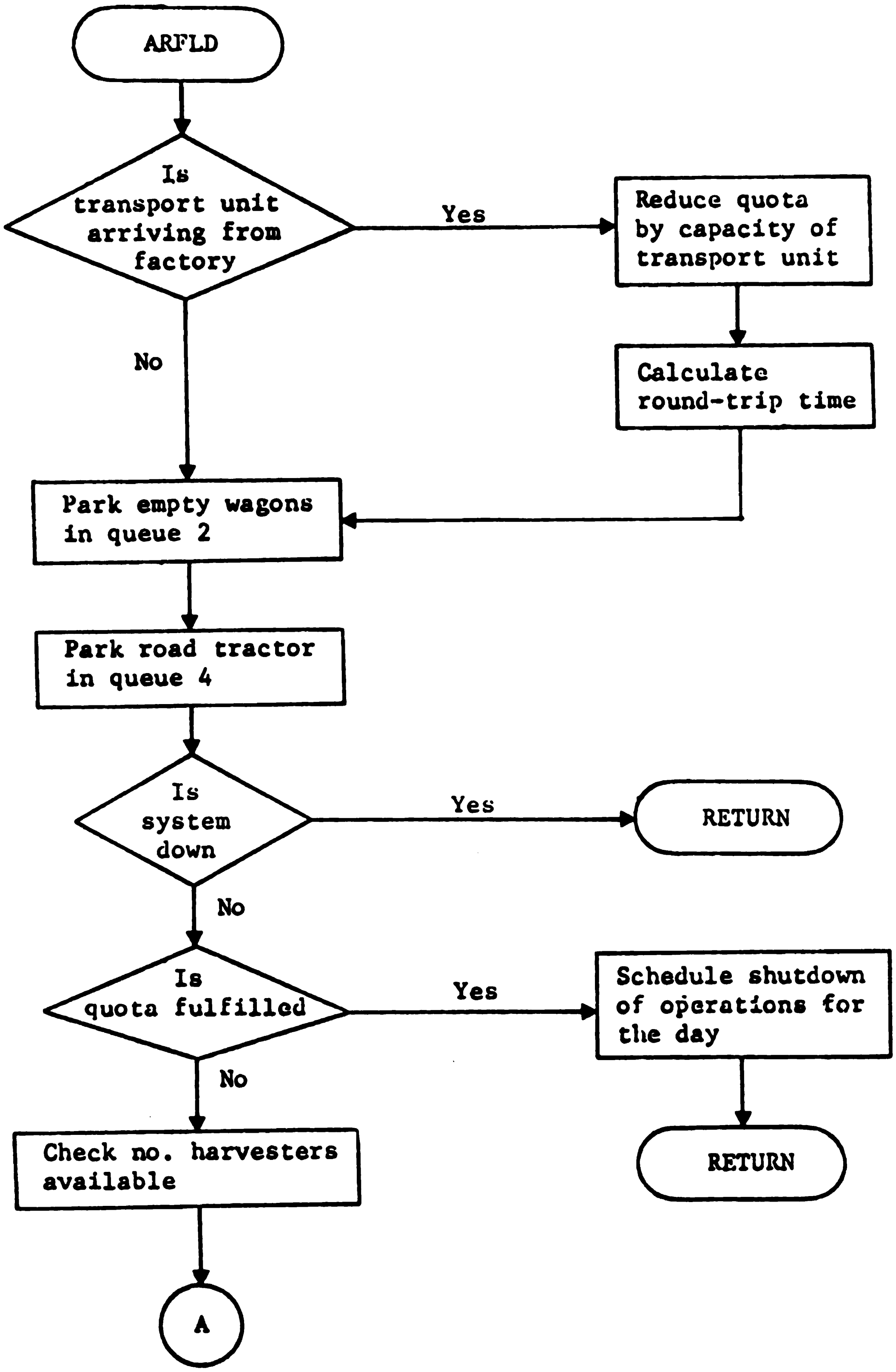


Figure 5.3. Flowchart through subroutine ARFLD

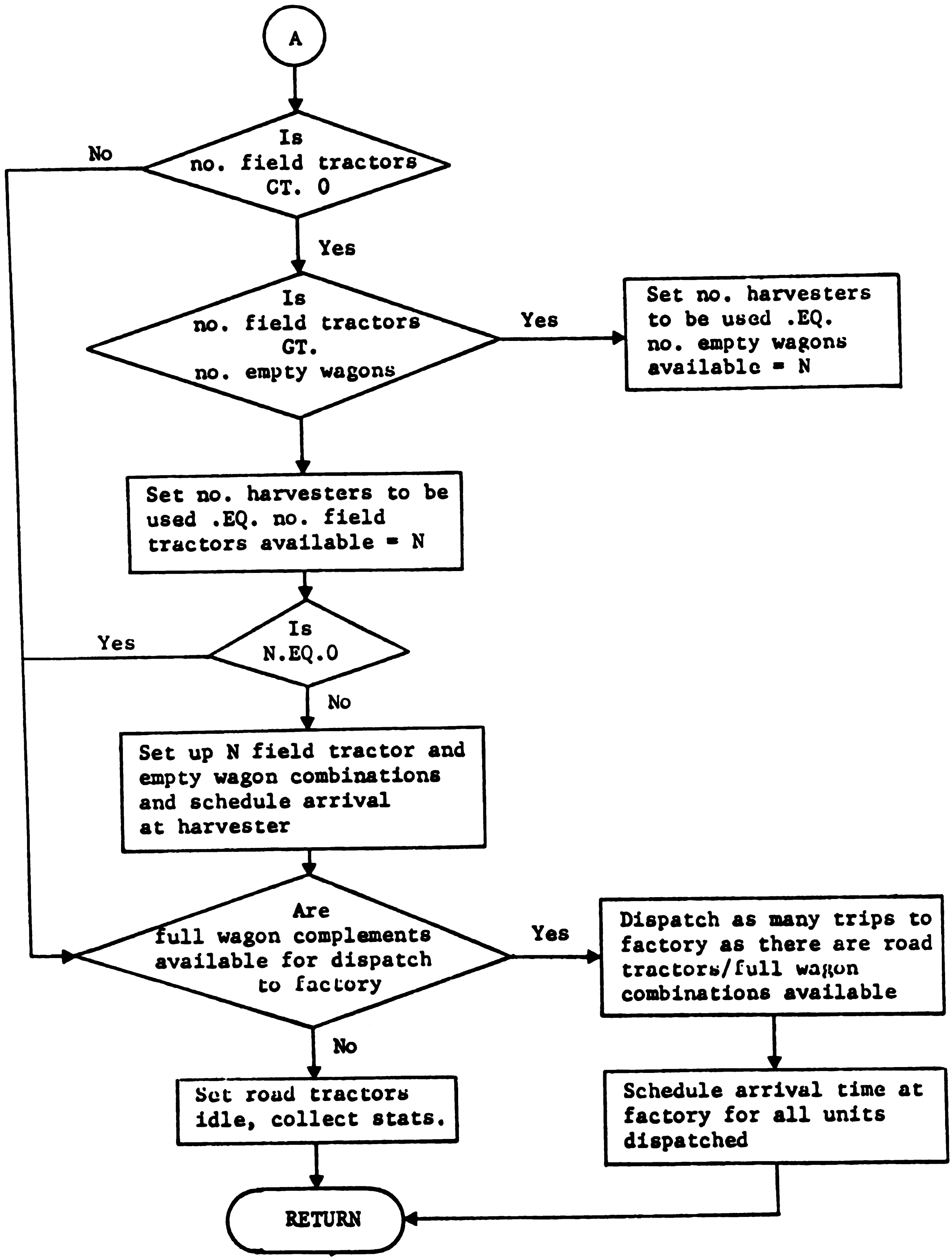


Figure 5.3. (continued)

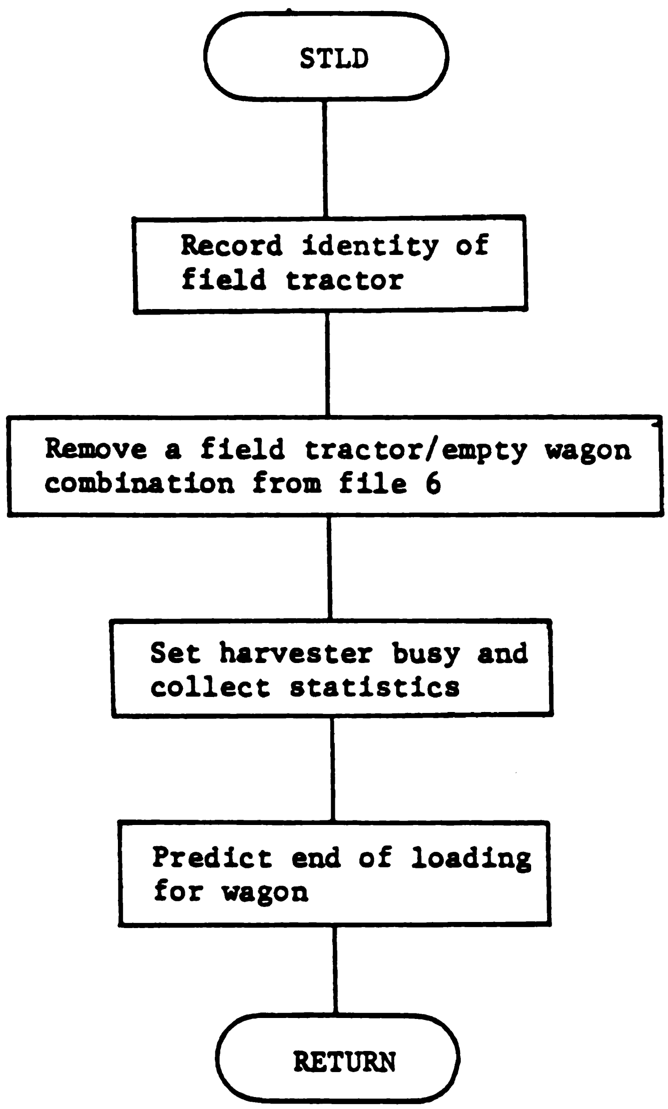


Figure 5.4 Flowchart through subroutine STLD

Table 5.4. Statistical distributions used for activity times in model FIELDOP

Activity	Entity involved	Activity time calculated	Units	Distribution type	Parameter set number
Loading	Harvester	Loading time per wagon	Minutes	Gamma	1
Road travel full	Road tractor & 2 wagons	Travel speed to factory	Kilometres per hour	Normal	2
Weighing and unloading in factory	Road tractor & 2 wagons	Residence time at factory	Minutes	Gamma	3
Road travel empty	Road tractor & 2 wagons	Travel speed to field	Kilometres per hour	Normal	4
Field travel empty	Field tractor & 1 wagon	Travel time to harvester	Seconds	Erlang	5
Field travel full	Field tractor & 1 wagon	Travel time to queue of full wagons	Seconds	Erlang	6
Harvester idle time		Lapse time between end of loading 1 wagon and the start of loading the next	Minutes	Erlang	7

Table 5.5. Input parameters for distributions used in FIELDOP

Paramter Set	A	Min.	Max.	B	Dist. type	Entity
1	6.10	0.00	15.46	2.00	GAMMA	Loading time per wagon
2	12.74	6.44	24.62	5.89	NORMAL	Travel speed to factory
3	5.21	0.00	143.40	4.00	GAMMA	Factory yard residence time
4	23.27	19.31	32.18	4.02	NORMAL	Travel speed to field
5	0.02	0.00	429.00	1.88	ERLANG	Travel time to harvester
6	0.03	0.00	310.00	3.37	ERLANG	Travel time to full queue
7	0.06	0.00	102.30	1.00	ERLANG	Harvester idle time
8	7.89	6.05	18.00	3.20		Minimum observed times[1]
9	3.00	5.00	7.00			Distance to factory

[1]Minimum observed times reading from left to right refer to minimum loading time, minimum factory residence time, minimum travel time to and from the harvester, and minimum harvester idle time, respectively.

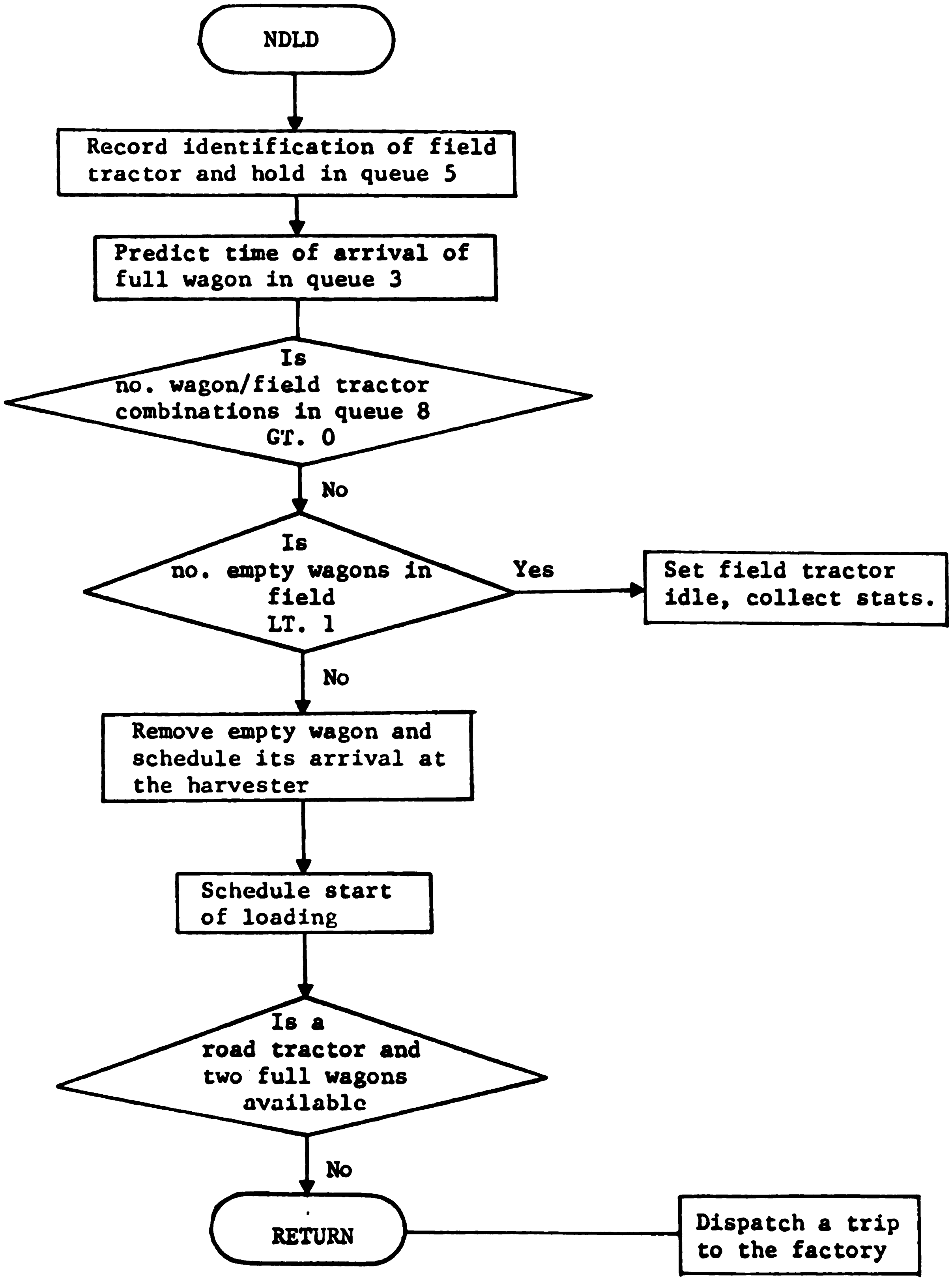


Figure 5.5. Flowchart through subroutine NDLD

Since the loaded wagon spends some time travelling across the field before it reaches the queue of full wagons, its time of arrival in the queue is predicted by sampling the Erlang distribution of the travel time to this queue using parameter set #6. This time is recorded as attribute 4 (see Table 5.1).

If there is a field tractor and empty wagon combination waiting in File 8, it is removed and set in motion towards the harvester. Its time of arrival at the harvester is scheduled by sampling the Erlang distribution for travel time to the harvester using parameter set #5. If there is no such combination in File 8, the harvester is set idle. The field tractor just released after depositing the full wagon is then combined with an empty wagon (if there is one available) and a start of loading event is initiated by setting the harvester busy.

If a road tractor and a complement of full wagons are available, a trip is dispatched to the factory. Its time of arrival at the factory is scheduled by sampling the Normal distribution for travel speed to the factory and combining the deviate obtained with the known distance to the factory to obtain the travel time to the factory. Based on numerous field observations, it takes an average of 3 minutes for a trip to be prepared for departure from the field, so 3 minutes are added to the current time TNOW when calculating the arrival time of a transport unit at the factory.

Subroutine ARHTR (Figure 5.6) simulates a field tractor and empty wagon combination approaching the harvester while it is busy loading another wagon. This occurs only if the number of field tractors in the system is greater than one. Therefore, subroutine ARHTR is called only if there are two or more field tractors assigned to a single harvester. In this case, holding a field tractor and empty wagon combination in Field 8 represents a situation where a wagon is being loaded and a second wagon is waiting very close behind so that it can start receiving cane as soon as the first wagon becomes full, without the harvester having to stop cutting.

Subroutine ARFCT (Figure 5.7) simulates the arrival of a transport unit at the factory, predicts its residence time by sampling the Gamma distribution of factory residence time using parameter set #3, and schedules the departure of the emptied unit from the factory.

Subroutine DPFCT (Figure 5.8) predicts the arrival of an empty transport unit at the field by sampling the Normal distribution of the travel speed to the field using parameter set #4, and combining the deviate obtained with the known distance between field and factory to arrive at a travel time. The returning transport unit is labelled as having delivered its load (ATRIB (12) = 1.0) and information on it is recorded in File 7.

Subroutine SHTDN (Figure 5.9) is used to close out all activities at the end of a shift or a work day. All entities are returned to their respective files and the future events file (File 1) is cleared in preparation for a new start at the commencement of the next shift or next day.

Subroutine STRTUP (Figure 5.10) is called to clear all of the GASP IV statistical data collection arrays in preparation for the new shift. If full wagons and road tractors are available at this time, trips are dispatched to the factory in accordance with the number of complete transport units available.

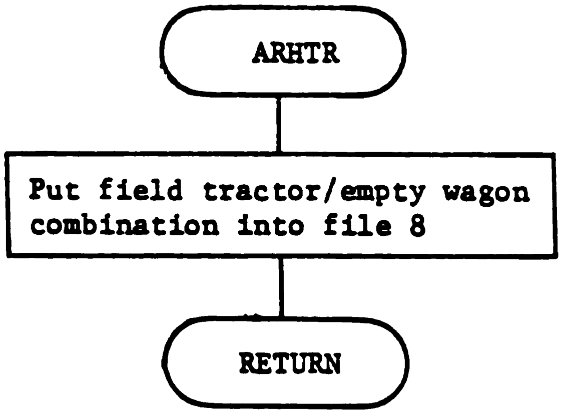


Figure 5.6 Flowchart through subroutine ARHTR

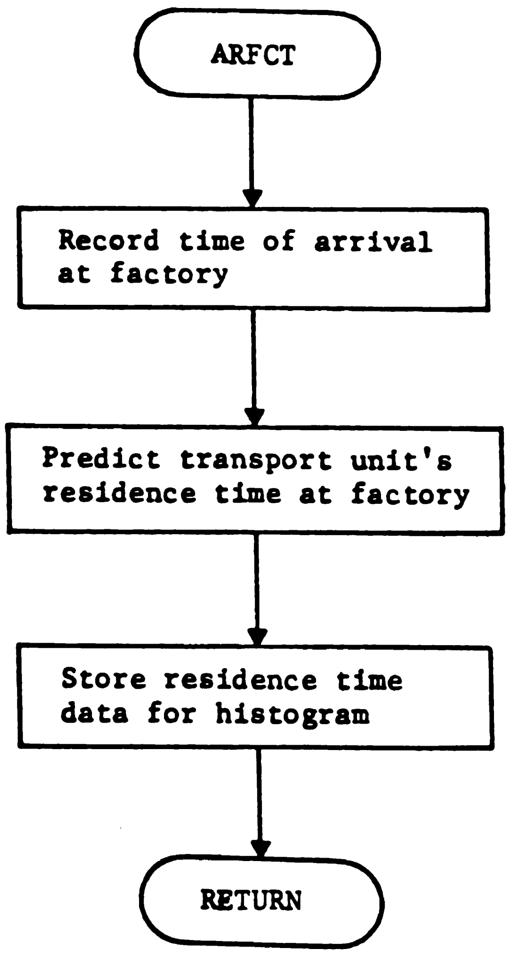


Figure 5.7 Flowchart through subroutine ARFCT

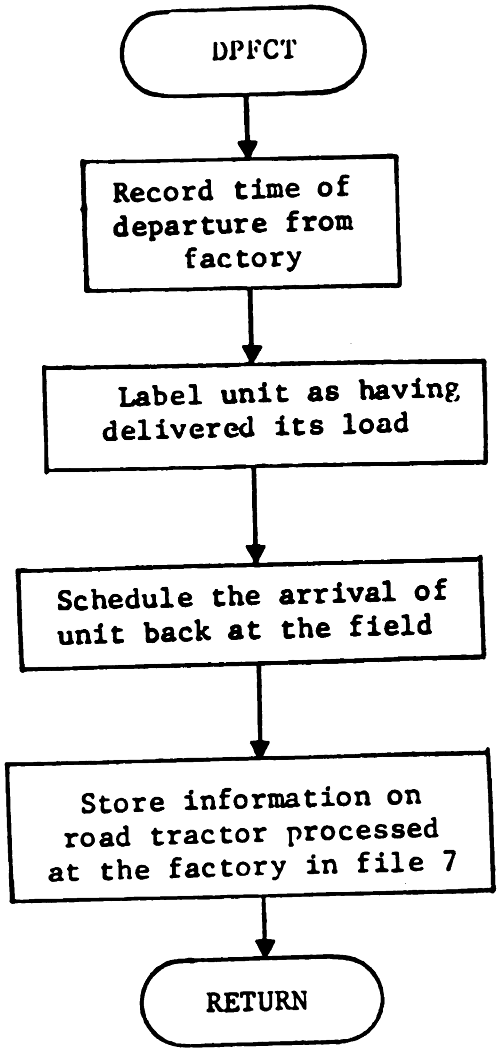


Figure 5.8 Flowchart through subroutine DPFCT

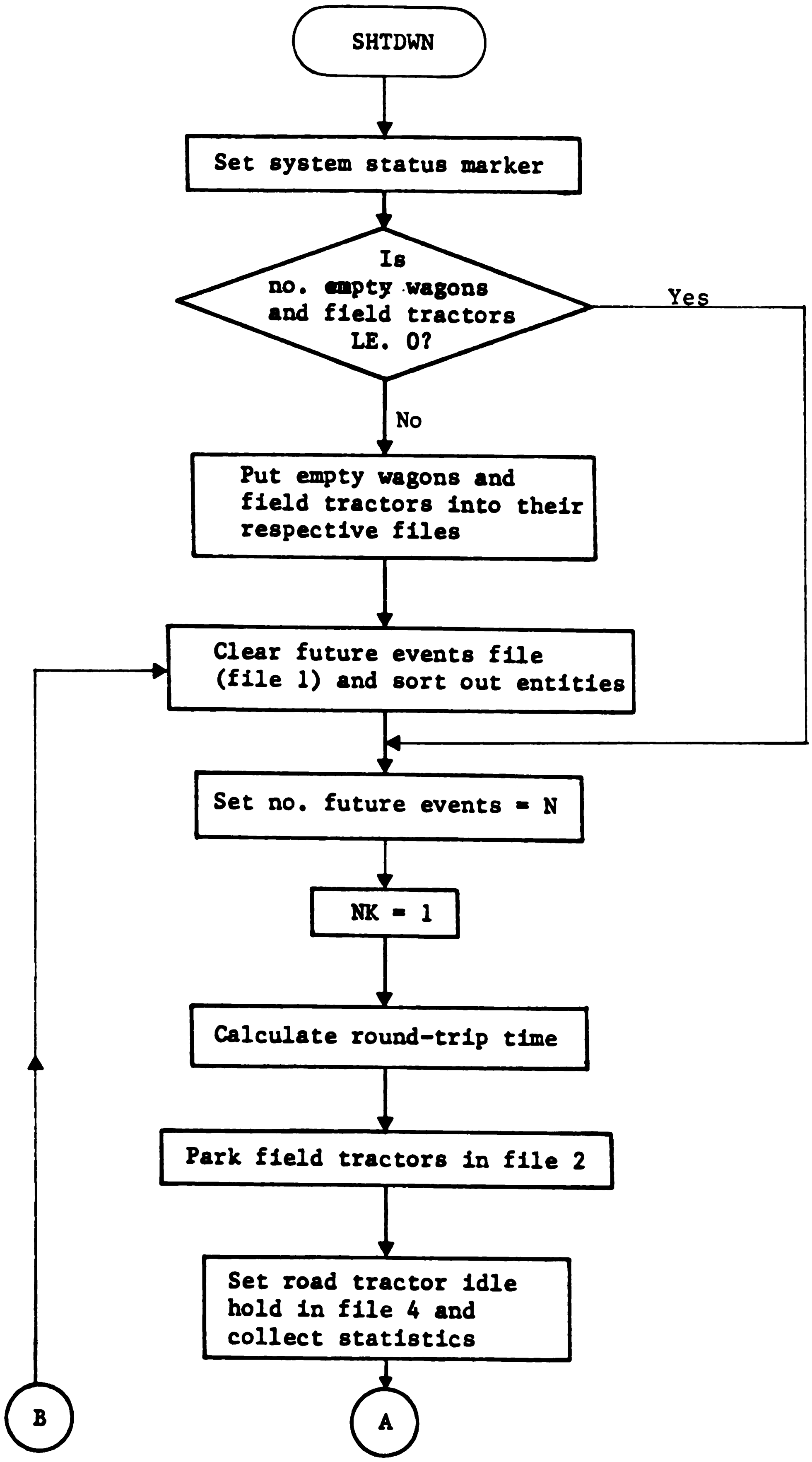


Figure 5.9 Flowchart through subroutine SHTDN

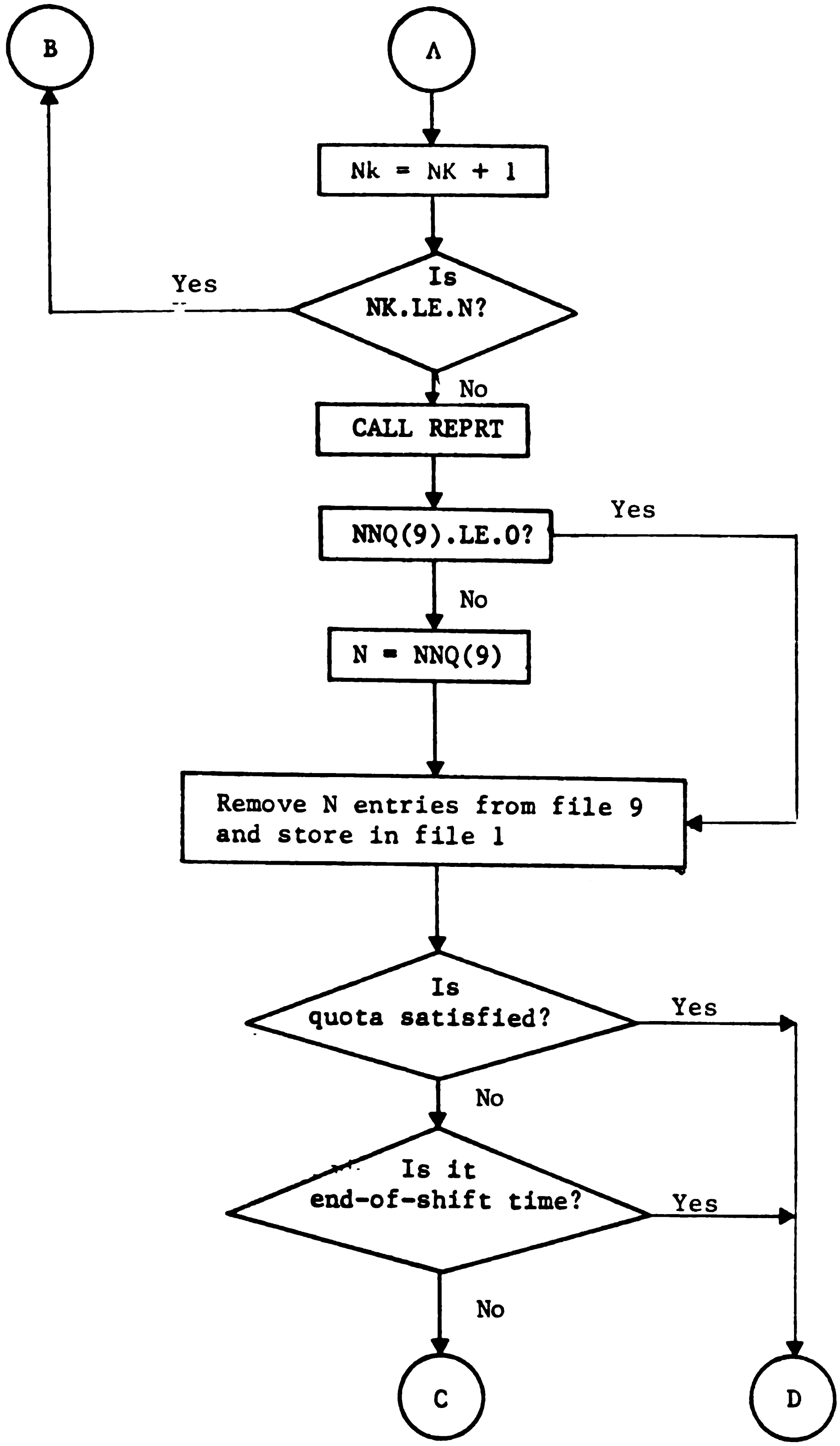


Figure 5.9 (continued)

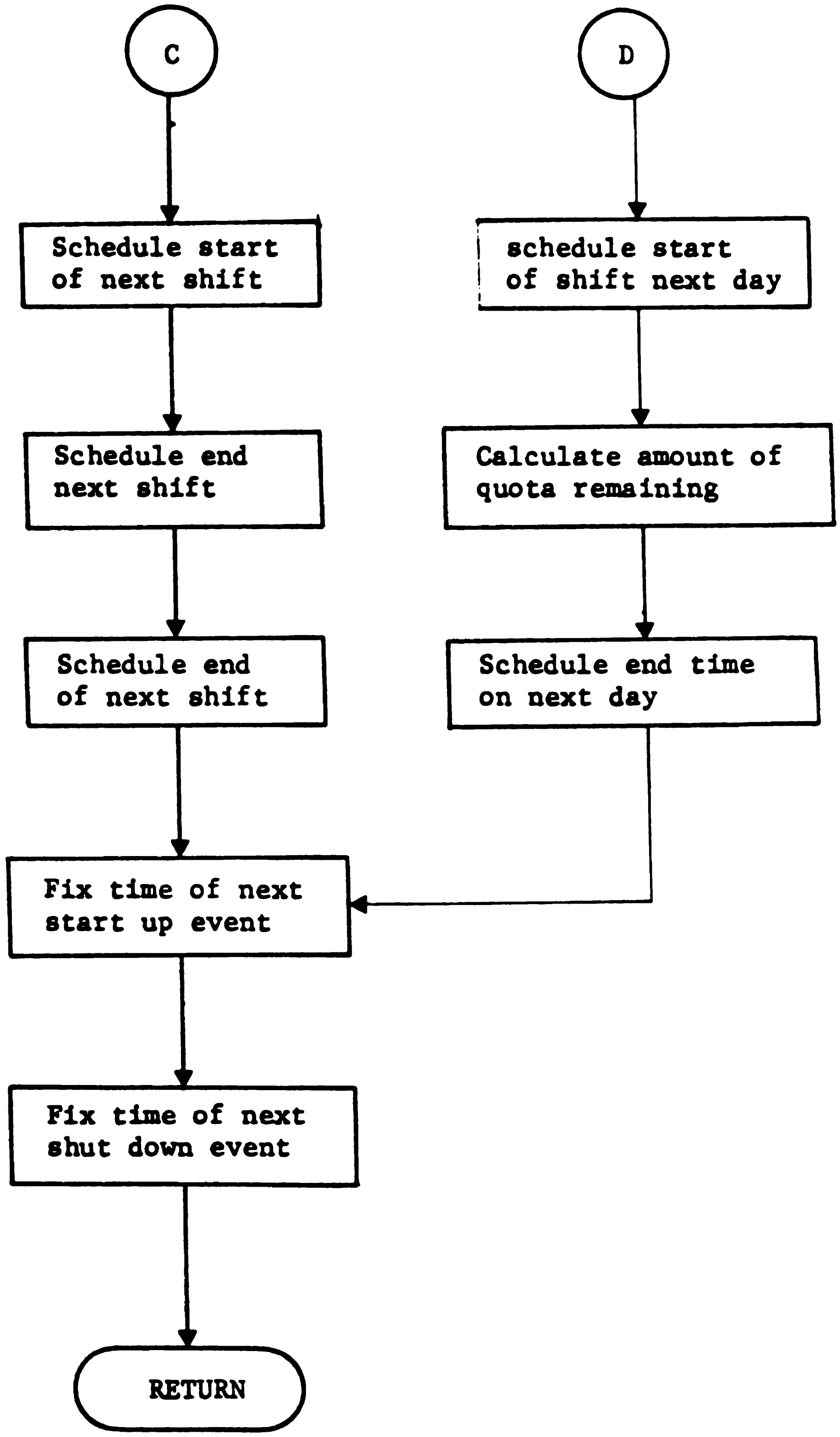


Figure 5.9 (continued)

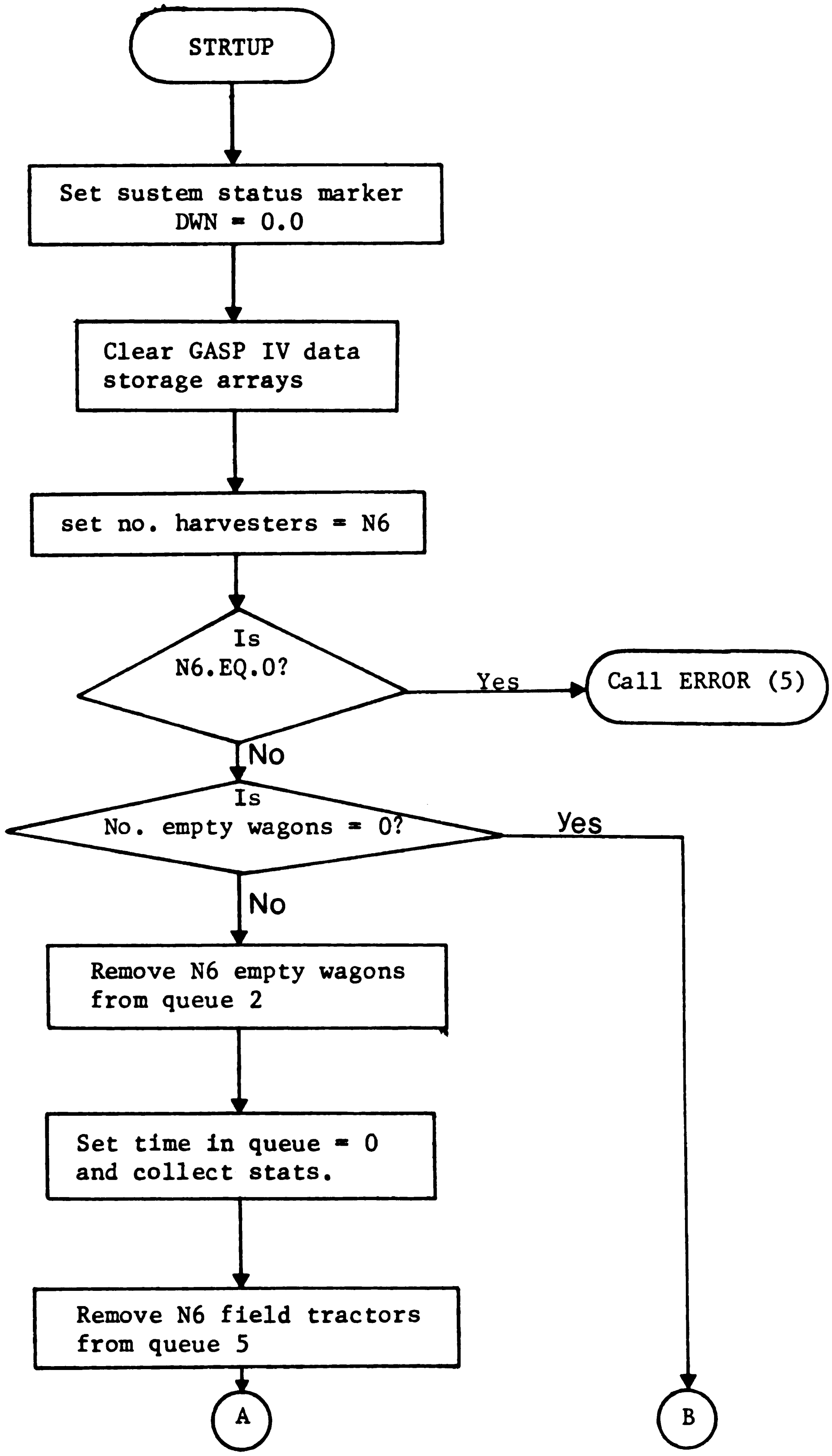


Figure 5.10 Flowchart through subroutine STRTUP

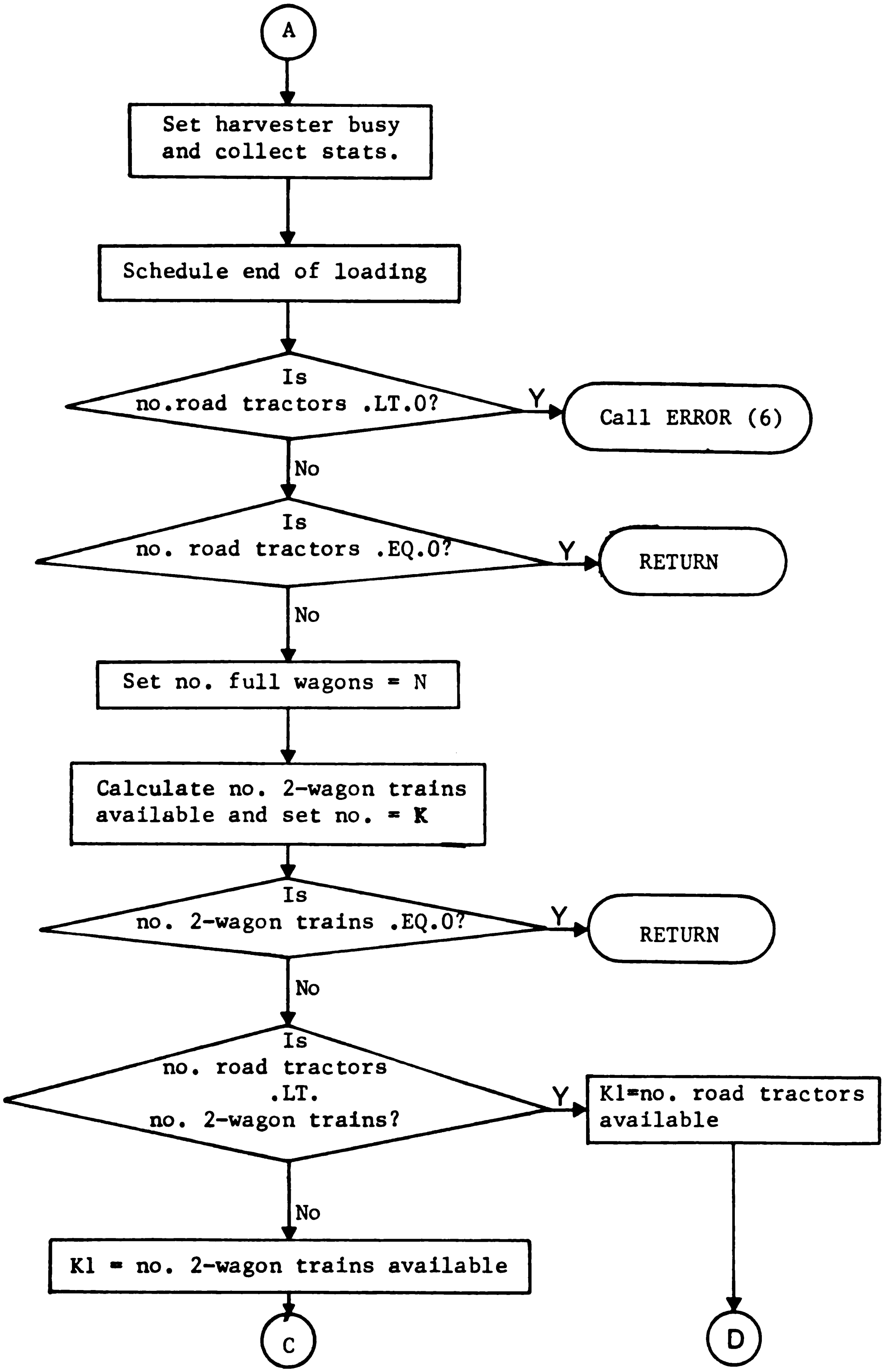


Figure 5.10 (continued)

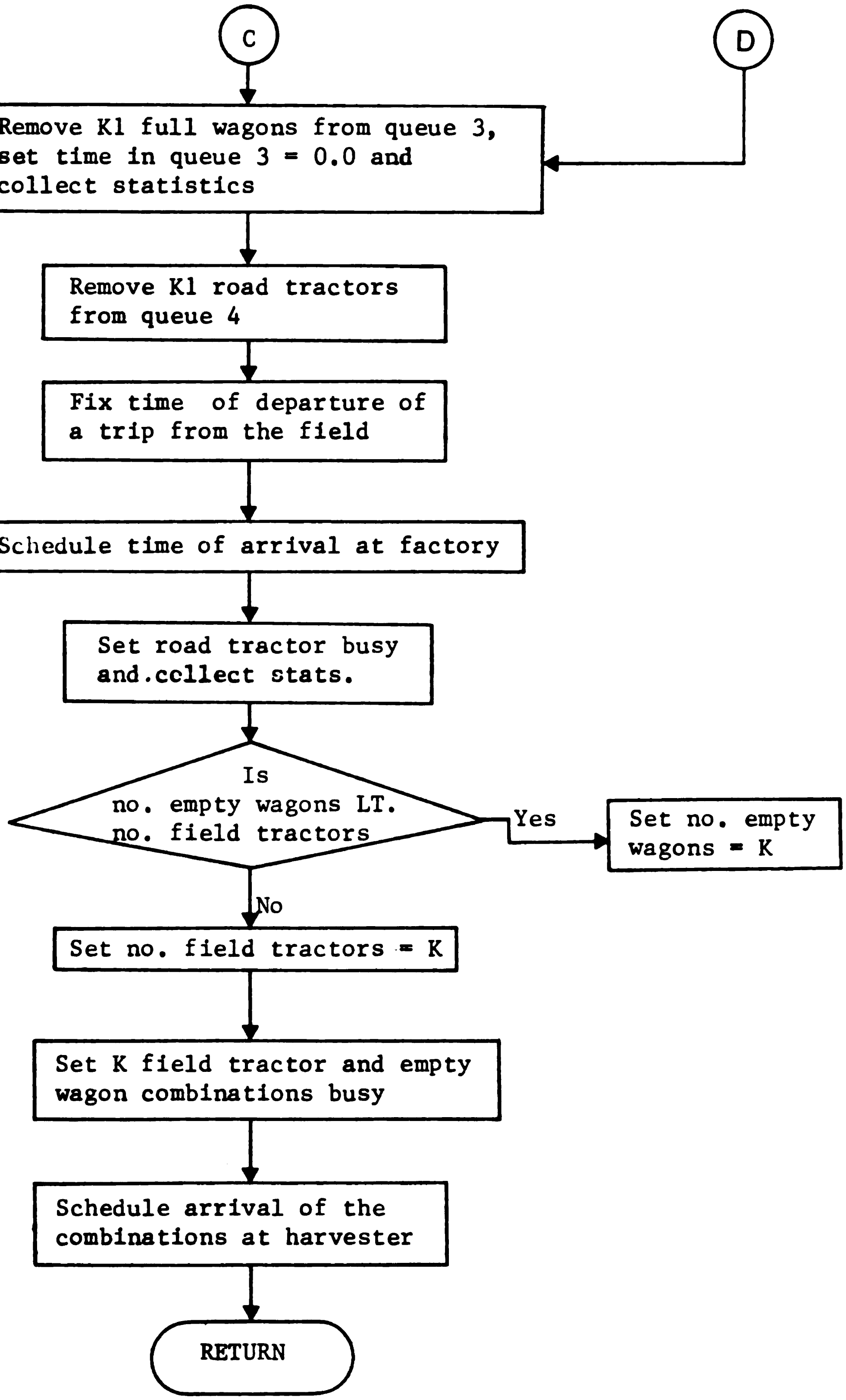


Figure 5.10 (continued)

Table 5.6. FIELDOP variables monitored by GASP IV subroutine COLCT

Variable Symbol	Description
RTRIP	The total trip time of the road tractor from the field to the factory and back.
TIQE	The time spent by an empty wagon at the field waiting to be loaded.
TIQF	The time spent by a full wagon at the field waiting to be taken to the factory.
TIQW	The time spent by a field tractor and wagon combination waiting to be loaded when more than one field tractor is used per harvester.

Table 5.7. FIELDOP variables monitored by GASP IV subroutine TIMST

Variable Symbol	Entity	Description
BUSHT (I)	Harvester	Utilization of harvester number I defined by attribute 8.
BUSFT (J)	Field tractor	Utilization of field tractor number J defined by attribute 9.
BUSRT (K)	Road tractor	Utilization of road tractor number K defined by attribute 10.

5.4. The Factory Yard Simulation Model

5.4.1. The System Environment

The system environment for this model consists of the following exogenous variables:

- Number of cane harvesters in operation at any given time
- Number of road tractors, field tractors and wagons operating in locations from which the cane is dispatched to the factory
- The field conditions at these locations
- Road conditions along routes from the field to the factory.

All of these factors affect the total number of transport units dispatched to the factory which, in turn, affects the inter-arrival time of transport units at the factory (see Figure 5.11 for causal loop diagram).

5.4.2. Entities

The entities considered for this model are:

1. The weigh scale
2. The chopped cane unloader (crane)
3. The whole cane unloader (hoist)
4. The chopped cane transport units (2 wagons and 1 road tractor)
5. The whole cane transport units (2 trailers and 1 road tractor)

As was the case in the field operations model, operating personnel of transport units are considered to be integral parts of those units and,

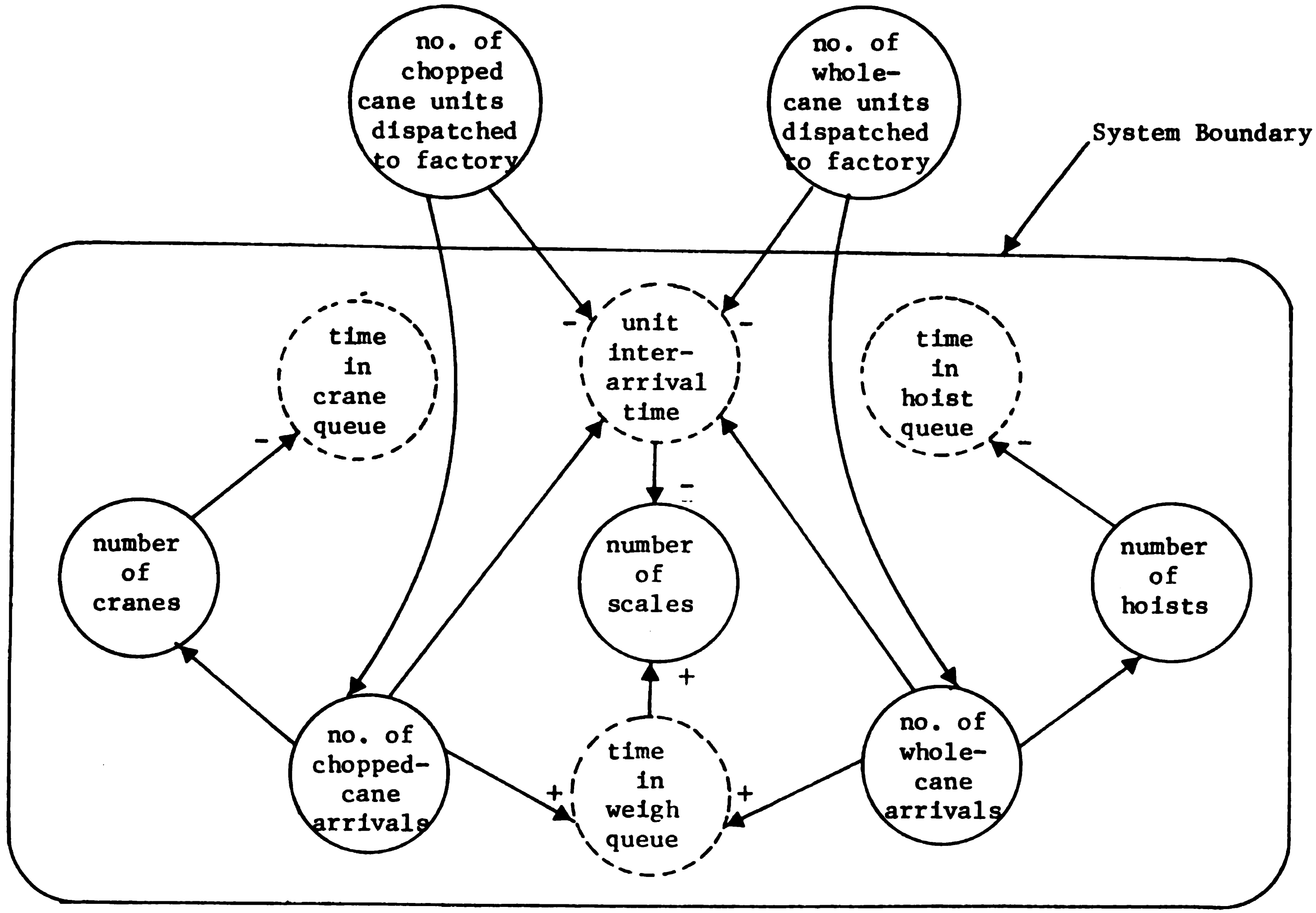


Figure 5.11. Causal loop diagram for the factory yard system

as such, are not modelled individually. In addition, since a transport unit is handled intact throughout the factory yard process, individual wagons or trailers are not treated as entities.

5.4.3. Endogenous Variables

The endogenous variables generated within the system boundary are as follows:

1. Time spent in the weigh queue
2. Time spent by a unit in the chopped-cane unloader queue (crane)
3. Time spent by a unit in the whole cane unloader queue (hoist).

5.4.4. Output Variables

These include the endogenous variables listed above and the following:

1. Average time a unit spends in the factory yard subsystem
2. Total number of units through the system
3. Number of units processed by the scale server
4. Number of units processed by the crane unloader
5. Number of units processed by the hoist unloader
6. Maximum number of units in the scale queue
7. Minimum number of units in the chopped cane unloader queue
8. Maximum number of units in the whole cane unloader queue
9. Utilization of the scale server

Table 5.8. List of NON-GASP variables used in FACYARD

Symbol	Definition
XISYS	Number in system
TISYS	Time in system
XVW	Number of units through yard
KJ	Local assessment of type of unit
KL	Local assessment of type of unloader
TIQ2	Time in queue for scale
TIQ3	Time in queue for crane (chopped cane)
TIQ4	Time in queue for hoist (whole cane)
BUS2*	Status of scale
BUS3*	Status of crane (chopped cane unloader)
BUS4*	Status of hoist (whole cane unloader)

*Values of 0.0 = free; 1.0 = busy for these variables.

Table 5.9. Files used in model FACYARD

File Number (I)	Entities	KKRNK (I)	IINN (I)
1	Future events	4	1
2	Scale queue	4	3
3	Chopped cane unloader queue	4	3
4	Whole cane unloader queue	4	3

Table 5.10. Statistical distributions used for activity times in model FACYARD

Event	Distribution type	Parameter set	Random number stream
Inter-arrival time	Exponential	1	1
Weigh time	Erlang	2	2
Unload time (crane)	Erlang	3	3
Unload time (hoist)	Erlang	4	3

Table 5.11. Attributes used in model FACYARD

Attribute number	Description	Value
1	Event time	
2	Event code	1 - Arrival 2 - End of weighing 3 - End of unloading
3	Time into system	
4	Time into weigh queue	
5	Type of unit	1 - Chopped cane 2 - Whole cane
6	Unloader type	1 - Chopped cane 2 - Whole cane
7	Unloader used	1 - Crane 2 - Hoist
8	Time into queue 3 (crane)	
9	Time into queue 4 (hoist)	

10. Utilization of the crane server

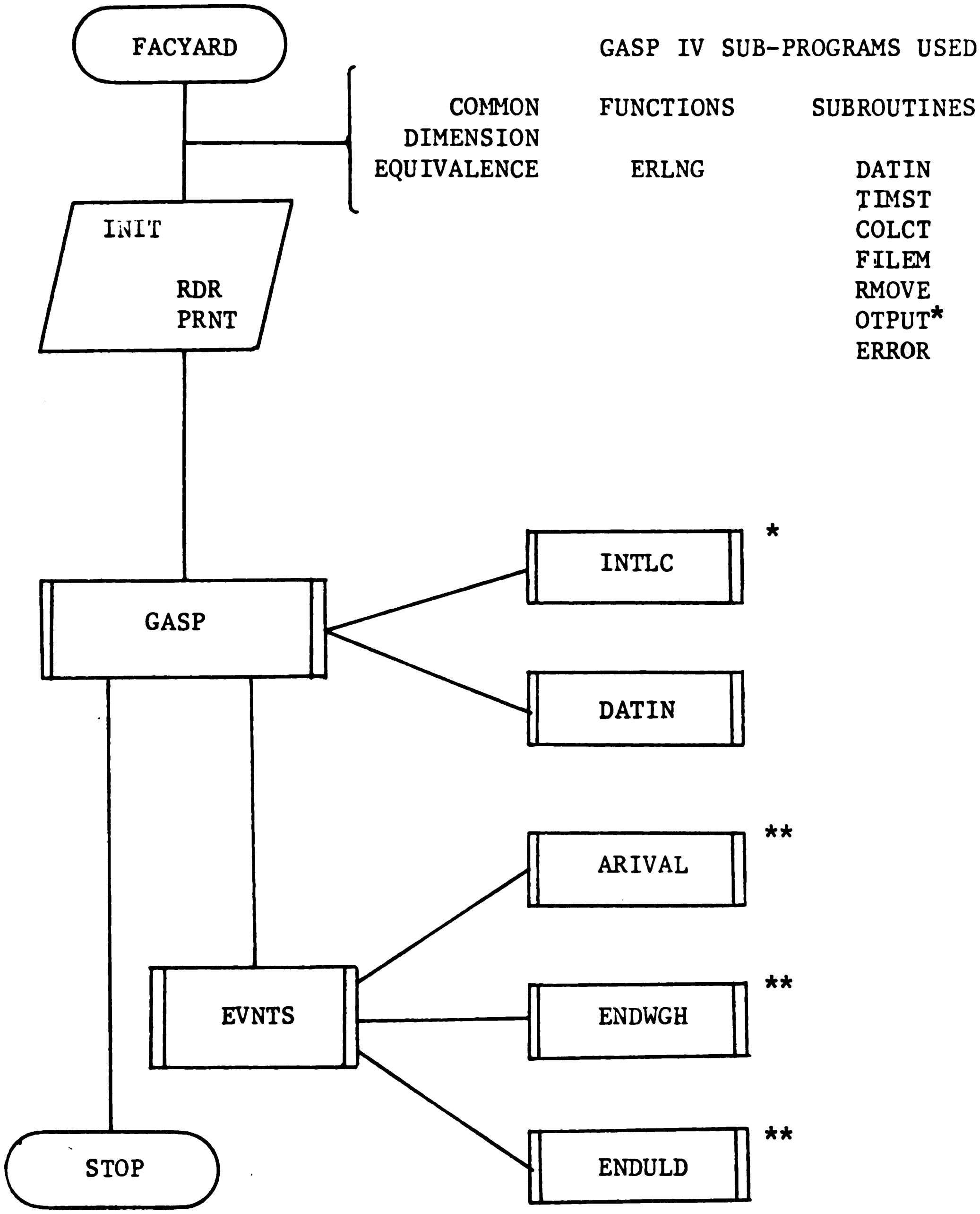
11. Utilization of the hoist server.

5.5. Factory Yard Simulation Program (FACYARD)

The system consists of an unlimited number of cane transport units which arrive randomly at the factory where they undergo two services: weighing and unloading. Two types of transport units arrive: chopped-cane wagons and whole-cane trailers. A transport unit consists of two wagons or two trailers and a road tractor and has a nominal carrying capacity of 10 tonnes. Current factory yard equipment consists of one crane for tipping chopped-cane units directly onto the feeder table and one hoist for unloading whole-cane and either stacking it or placing it directly onto the feeder table.

5.5.1. General Flow through Model FACYARD

The flowchart for model FACYARD is presented in Figure 5.12. The main program (user written) assigns appropriate values to the card reader and printer units and initializes the variables declared in the DIMENSION, COMMON and EQUIVALENCE statements, before making a call to the GASP IV executive subroutine, GASP. Subroutine DATIN and INTLC are then called from GASP to enter input data and establish initial conditions and performance criteria for the simulation. A successful return from DATIN is indicated by a print out of intermediate results in which the input data and initial values established for the variables are echoed. The executive routine GASP then calls subroutine EVNTS (IX) from which calls are made to the individual user-written event subroutines



* GASP IV SUBROUTINE (USER WRITTEN)
** USER SUBROUTINE

Figure 5.12. Flowchart through FACYARD

ARIVAL, ENDWGH or ENDULD, based on the value of the argument IX. In order to start the simulation, one arrival is scheduled for a chopped-cane transport unit at simulation time 0.0 and one for a whole-cane unit at time 0.5 minutes.

With IX = 1, subroutine ARIVAL is called to process the arriving transport unit (Figure 5.13). The type of unit just arriving is recorded and the next arrival of this type is scheduled by generating a random deviate from the Exponential distribution of inter-arrival times using the distribution parameters stored in parameter sets #1 and #2. The status of the scale is then checked. If free, it is set busy and an end-of-weighing event scheduled by generating a deviate from the Erlang distribution of weigh times using parameter set #3. If the scale is busy, the arrival is put into the queue to the weigh scale (queue 2) and its time of entering the queue is recorded.

With IX = 2, subroutine ENDWGH is called to handle transport units at the end of weighing (see Figure 5.14 for the flowchart of this routine). At the end of weighing, the transport unit just weighed is sent to either the crane or hoist unloader, depending on whether it is a chopped- or whole-cane unit. If the unloader is free, an end-of-unloading event is schedule by sampling the Erlang distribution using the appropriate parameter set for the unloader service time (Table 5.14). Otherwise, the weighed transport unit is put into the appropriate unloader queue and its time of entering the queue is recorded. The first unit standing in the scale queue is then removed and an end-of-weighing event scheduled for it. The time spent in the scale queue by this unit is then calculated by a call to the GASP IV subroutine COLCT.

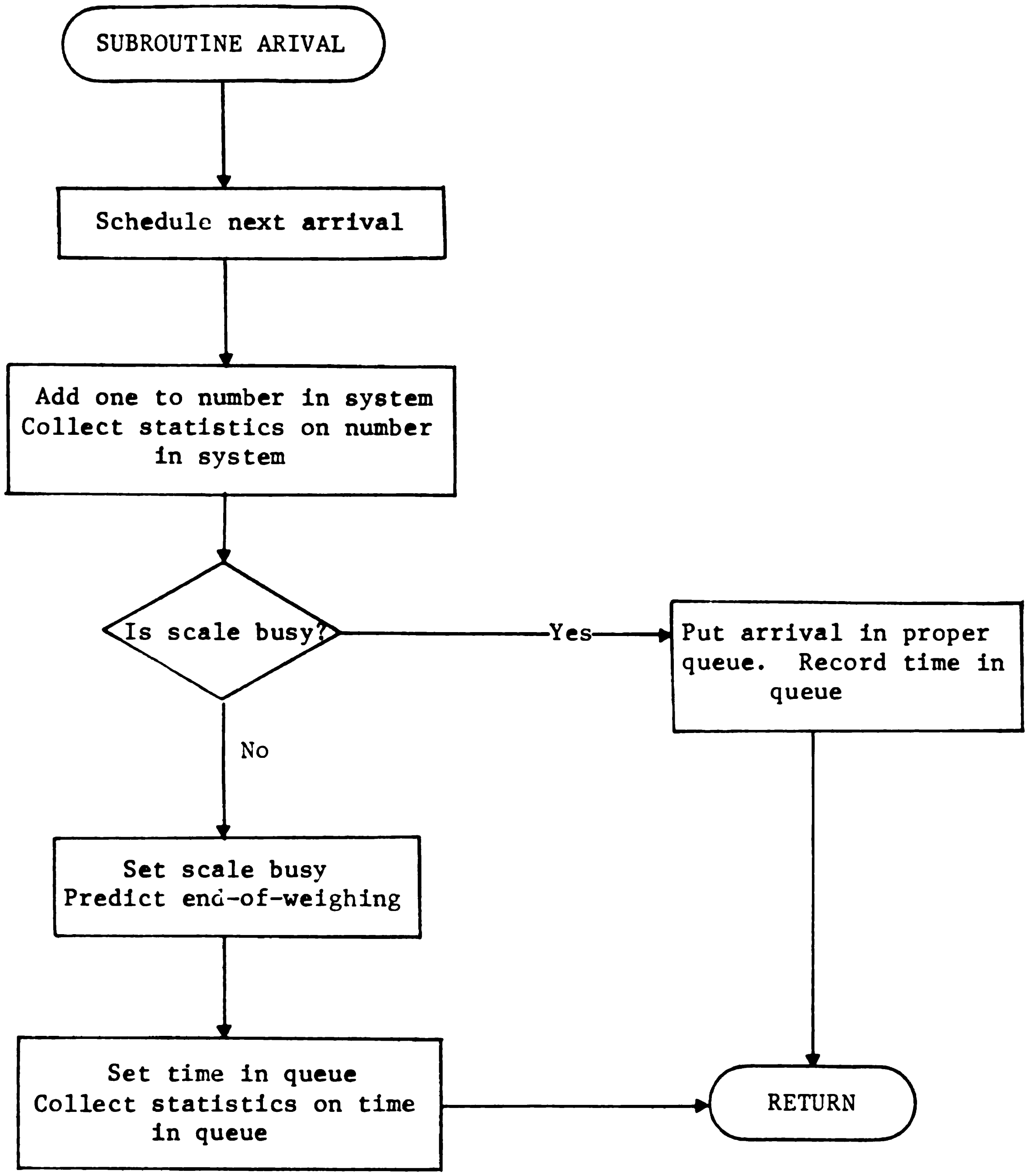


Figure 5.13. Flowchart of the event "arrival at factory"

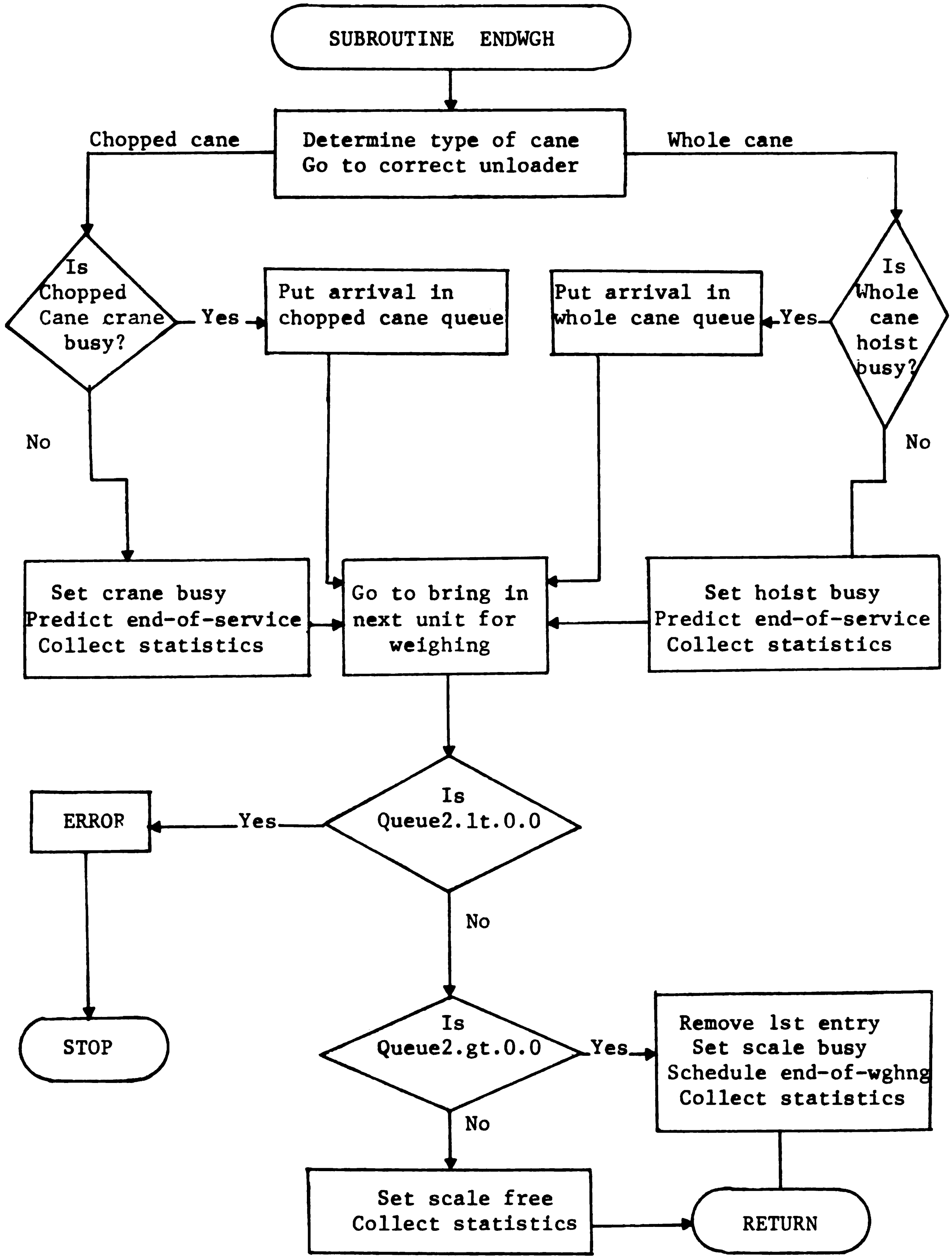


Figure 5.14. Flowchart of the event "end-of-weighing"

With IX = 3, subroutine ENDULD is called to handle units at the end of unloading (see Figure 5.15 for flowchart). The type of transport unit just unloaded is recorded and, since unloading is the last activity performed on the unit, the time the unit spent in the system is calculated by a call to the GASP IV subroutine TIMST and the number of transport units through the factory yard process is updated by one. The first unit in the queue to the appropriate unloader is then removed and an end-of-unloading event is scheduled for it. Subroutine COLCT is then called to calculate the time spent by this unit in the unloader queue.

The variables monitored by the GASP IV subroutines TIMST and COLCT in program FACYARD are listed in Tables 5.12 and 5.13, respectively, and a computer listing of the program is given in Appendix III.

5.5.2. Input Data for FACYARD

As mentioned earlier, the input data for FACYARD consists of the statistical distribution parameters determined for the various activities of the Factory Yard system, using the data analysis program (DATANAL) previously described. The input parameters used in the model are given in Table 5.14. For the Erlang distribution, A represents the scale factor and B the shape factor and the mean of the distribution is given by A x B. The EXPONENTIAL distribution is a special form of the ERLANG distribution in which the shape factor B is always equal to 1, so that A is, in fact, the mean of the distribution.

DATANAL not only outputs values for the scale and shape factors of the distribution, but also generates a sorted list of the observed

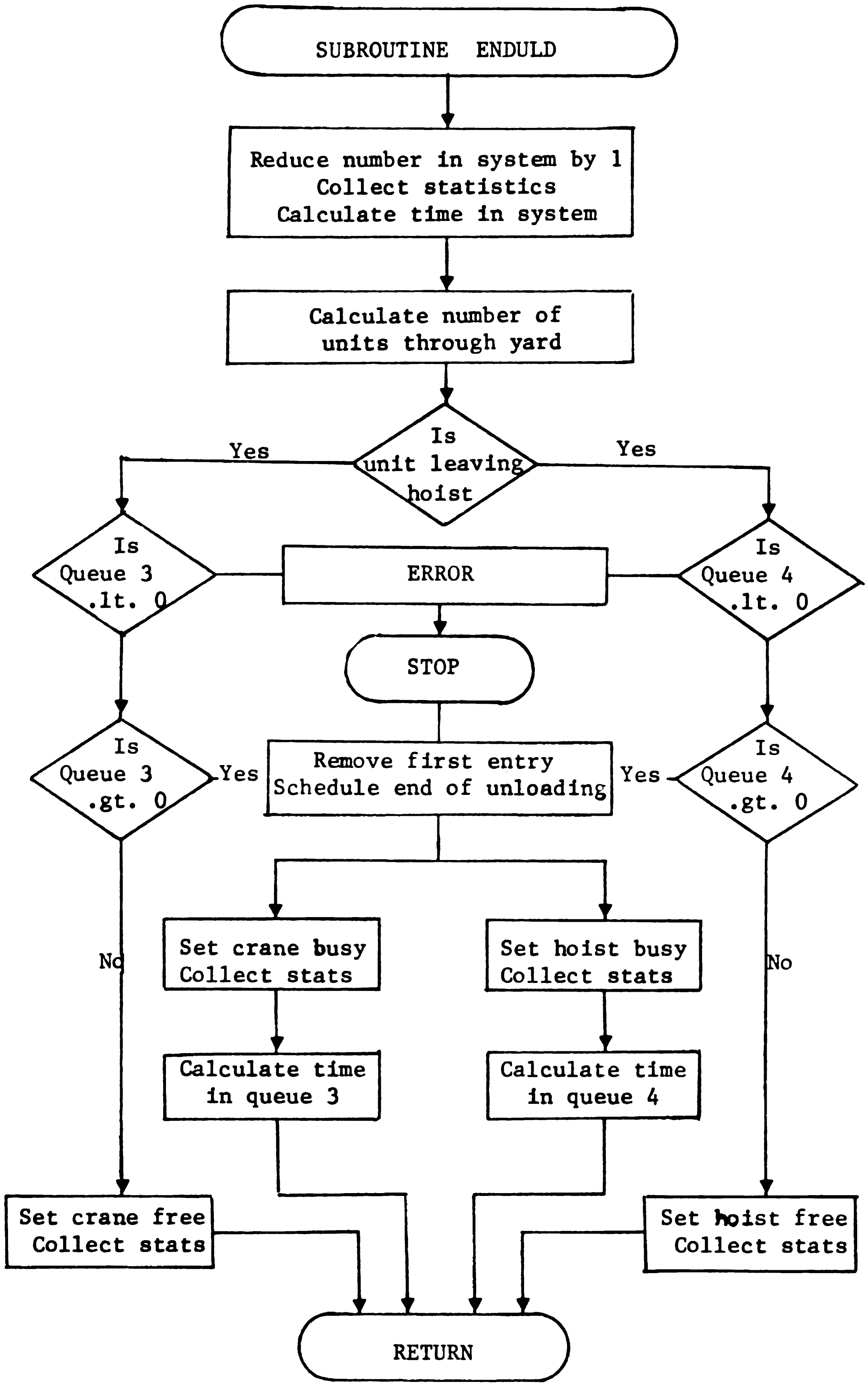


Figure 5.15. Flowchart of the event "End-of-Unloading"

Table 5.12. FACYARD variables monitored by GASP IV subroutine TIMST

Variable Symbol	Description
XISYS	The number of transport units in the factory yard system at any given time.
BUS2	The utilization of the weigh scale
BUS3	The utilization of the chopper-cane unloader (crane)
BUS4	The utilization of the whole-cane unloader (hoist)

Table 5.13. FACYARD variables monitored by GASP IV subroutine COLCT

Variable Symbol	Description
TISYS	The total time spent in the factory yard system by a transport unit
TIQ2	The time spent by a transport unit in the scale queue waiting to be weighed
TIQ3	The time spent by a chopped-cane transport unit in the queue to the chopped-cane unloader (crane) waiting to be unloaded
TIQ4	The time spent by a whole-cane transport unit in the queue to the whole-crane unloader (hoist) waiting to be unloaded.

Table 5.14. Input parameters and distributions used in FACYARD

Parameter Set	A	Min	Max	B	Distribution Type	Entity
1	7.10	0.0	54.6	1	EXPONENTIAL	Chopped-cane arrival
2	5.20	0.0	53.5	1	EXPONENTIAL	Whole-cane arrival
3	0.34	0.87	8.5	10.2	ERLANG	Scale
4	1.50	2.2	8.1	2.5	ERLANG	Crane unloader
5	0.92	1.8	4.8	3.1	ERLANG	Hoist unloader

data, thereby facilitating determination of the minimum and maximum values. Specification of these minimum and maximum observed values in the input data ensure the rejection of any random deviates, generated during the execution of FACYARD, which may fall outside the desired range.

CHAPTER 6

RESULTS AND DISCUSSION

6.1. Introduction

The standard output from GASP IV simulation models is in tabular and/or graphical form. Statistics for time-varying variables (such as the number of units through the system and the proportion of time each server is busy) are collected as a standard function of the GASP IV subroutine TIMST, provided that this subroutine is called by the user at the appropriate times. Similarly, regular statistics for time-persistent variables (such as the time spent in each queue and the total time spent by a unit in the system) are routinely collected by appropriate calls to the GASP subroutine COLCT.

The GASP IV output function also provides detailed and summary information on the entries in each file, a file being representative of a specific service queue in the real system. Statistics provided on the files gives the maximum and minimum numbers of units in each queue for the duration of the simulation, as well as the current numbers of units in each queue at the end of the simulation period.

6.2. Results from the Factory Yard Simulation Model

Four alternative modes of factory yard operations were simulated for Carrington Sugar Factory. The first one featured the yard in its current configuration with a single weigh scale, a single queue to this scale and two unloading facilities; a crane for tipping chopped-cane transport units and an overhead hoist for unloading whole cane. The simulation time was 700 minutes, or the average length of a normal work day.

The second alternative was similar to the first, except that the daily work period was extended from 11 1/2 hours (700 minutes) to 16 hours (960 minutes).

The third alternative simulated a yard configuration with two weigh scales accepting cane from a single arrival queue over the normal work period of 700 minutes. Arriving cane transport units proceed to either scale, depending on which one first became available.

Like alternative three, the fourth alternative simulated a configuration with two weigh scales. In this case, however, each scale had its own queue. Scale #1 was used exclusively for weighing chopped-cane transport units and scale #2 for weighing whole-cane units.

In order to accommodate the additional scale in the case of alternative 3, and the additional scale and queue in the case of alternative 4, a number of changes were made in the coding of the FACYARD subroutines ARIVAL and ENDWGH. Fortran listings of these modified subroutines are given in Appendix III. The variables BUS5 and TIQ5 refer to the additional scale and queue respectively, and the service time distribution of the second scale was assumed to be identical to that of the first.

Table 6.1. Output from Model FACYARD for Current Configuration of Carrington Factory (Simulation time = 700 minutes)

STATISTICS FOR VARIABLES BASED ON OBSERVATION

VARIABLE	MEAN	STD. DEV.	CV	MIN	MAX	OBS	TIME IN
TISYS	73.98	25.61	0.35	6.05	119.40	210	System
TIQ2	64.71	25.52	0.38	0.00	113.80	212	Scale queue
TIQ3	0.30	0.77	2.61	0.00	4.61	83	Crane queue
TIQ4	0.24	0.58	2.43	0.00	2.61	128	Hoist queue

STATISTICS FOR TIME-PERSISTENT VARIABLES

VARIABLE	MEAN	STD. DEV.	MIN	MAX	CUR. VALUE	NAME
XISYS	23.81	7.02	0.00	37.00	29.00	No. in system
BUS2	1.00	0.06	0.00	1.00	1.00	Scale
BUS3	0.41	0.49	0.00	1.00	0.00	Crane unloader
BUS4	0.51	0.50	0.00	1.00	1.00	Hoist unloader

ENTRIES IN FILE STORAGE AREA (SERVICE QUEUES)

VARIABLE	MEAN	STD. DEV.	MAX	CUR. NO.	NAME
Q1	3.91	0.54	5.0	4.0	Future events
Q2	21.82	6.98	35.0	27.0	Scale queue
Q3	0.04	0.19	2.0	0.0	Crane queue
Q4	0.04	0.21	1.0	0.01	Hoist queue

6.2.1. FACYARD Results for Current Yard Configuration

The output from model FACYARD for this configuration is shown in Table 6.1. For purposes of model verification, values obtained from this simulation output were compared with actual, observed values for selected system performance indicators. The comparison is presented in Table 6.2 below:

Table 6.2. Comparison of observed and simulated values for selected system performance indicators.

Performance Indicator	Observed	Simulated	% Difference
Mean factory residence times	67.86	73.98	8.27
Maximum factory residence times	128.41	119.40	7.55
Mean time in scale queue	63.27	67.41	6.14
Maximum time in scale queue	122.31	113.80	6.95
Mean scale service time	3.58	3.76	4.80
Maximun time in crane queue	5.01	4.61	7.80
Maximum time in hoist queue	2.86	2.61	9.20

In all cases the difference between the observed and simulated values of the system performance indicators was less than 10 percent, verifying that the model adequately represented the real life system.

A study of Table 6.1 reveals that the main bottleneck of the factory yard system, in its current configuration, is the weighing operation. This is evidenced by the very high utilization factor (1.00) for the scale, by the average time spent by a unit waiting in the scale queue

(64.7 minutes) and by the length of the queue to the scale. The average number of transport units in the queue to the scale at any time during the day was 22; the minimum number of units in the queue was 5 and, at the end of the working day, some 27 units were standing in line waiting to be weighed. In contrast, the utilization factors of 0.41 for the chopped-cane crane and 0.51 for the whole-cane hoist, indicate substantial under-utilization of both of these unloaders. The total number of transport units passing through the system daily was 210, of which 83 were chopped-cane units.

6.2.2. FACYARD Results for Extended Work Period

The output from the model for the extended work period is presented in Table 6.3. There was an increase in the total number of units handled by the system to 289, 112 of which were chopped-cane units. The scale was again busy 100 percent of the time and there were 37 transport units awaiting service by the scale at the end of the day. Units spent an average of 83 minutes in the system as a whole and an average of 76.6 minutes in the scale queue. The chopped-cane unloader was utilized slightly less (39 percent of the time) and the whole-cane hoist slightly more (53 percent of the time).

6.2.3. FACYARD Results for Configuration with 1 Weigh Queue and 2 Weigh Scales

Table 6.4 shows the output from the model for this arrangement. In this case a total of 236 transport units were serviced by the system, 141 whole-cane units and 95 chopped-cane units. Scale #1 was busy 55

Table 6.3. Output from model FACYARD for extended work period at Carrington Factory (Simulation time = 960 minutes).

STATISTICS FOR VARIABLES BASED ON OBSERVATION

VARIABLE	MEAN	STD. DEV.	CV	MIN	MAX	OBS	TIME IN
TISYS	82.83	28.20	0.34	0.05	143.70	289	System
TIQ2	76.63	28.55	0.37	0.00	138.20	291	Scale queue
TIQ3	0.27	0.74	2.74	0.00	4.61	112	Crane queue
TIQ4	0.28	0.60	2.15	0.00	2.61	178	Hoist queue

STATISTICS FOR TIME-PERSISTENT VARIABLES

VARIABLE	MEAN	STD. DEV.	MIN	MAX	CUR. VALUE	NAME
XISYS	27.53	8.84	0.00	45.00	39.00	No. in system
BUS2	1.00	0.05	0.00	1.00	1.00	Scale
BUS3	0.39	0.49	0.00	1.00	1.00	Crane unloader
BUS4	0.53	0.50	0.00	1.00	0.00	Hoist unloader

ENTRIES IN FILE STORAGE AREA

VARIABLE	MEAN	STD. DEV.	MAX	CUR. NO.	NAME
Q1	3.91	0.53	5.0	4.0	Future events
Q2	2.53	8.81	43.0	37.0	Scale
Q3	0.04	0.18	2.0	0.0	Crane queue
Q4	0.05	0.22	1.0	0.0	Hoist queue

Table 6.4. Output from model FACYARD for configuration with 1 weigh queue and 2 scales (simulation time = 700 minutes).

STATISTICS FOR VARIABLES VASED ON OBSERVATION

VARIABLE	MEAN	STD. DEV.	CV	MIN	MAX	OBS	TIME IN
TISYS	9.00	3.54	0.34	3.85	21.32	236	System
TIQ2	0.93	1.57	1.69	0.00	9.15	239	Scales queue
TIQ3	1.63	2.89	1.77	0.00	11.06	95	Crane queue
TIQ4	1.75	2.39	1.36	0.00	10.99	143	Hoist queue

STATISTICS FOR TIME-PERSISTENT VARIABLES

VARIABLE	MEAN	STD. DEV.	MIN	MAX	CUR. VALUE	NAME
XISYS	3.07	1.96	0.00	9.00	3.00	No. in system
BUS2	0.55	0.50	0.00	1.00	0.00	Scale #1
BUS3	0.47	0.50	0.00	1.00	1.00	Crane unloader
BUS4	0.57	0.49	0.00	1.00	1.00	Hoist unloader
Bus5	0.65	0.48	0.00	1.00	1.00	Scale #2

ENTRIES IN FILE STORAGE AREA (SERVICE QUEUES)

VARIABLES	MEAN	STD. DEV.	MAX	CUR. NO.	NAME
Q1	4.16	1.31	9.0	4.0	Future events
Q2	0.32	0.86	6.0	0.0	Scale queue
Q3	0.22	0.60	4.0	0.0	Crane queue
Q4	0.37	0.74	4.0	1.0	Hoist queue

percent of the time and scale #2 65 percent of the time. The utilization factors for the crane and hoist unloaders were 0.47 and 0.57, respectively. The average time spent by a transport unit in the factory yard system and in the queue to the scale both fell sharply to 9 minutes and 0.93 minites, respectively, and all transport units arriving at the factory during the day were serviced.

6.2.4. FACYARD Results for Configuration with 2 Weigh Queues and 2 Weigh Scales

Table 6.5 presents the results obtained for this configuration. Some 236 transport units passed through the system daily. Of these, 95 were chopped-cane units. The average residence time at the factory for a transport unit was 9 minutes, the average time spent by a chopped-cane unit in the queue to scale #1 was 1.8 minutes; and the average time spent by a whole-cane unit in the queve to scale #2 (95) was 1.2 minutes. Scale #1 (the chopped-cane scale) was busy 45 percent of the time and scale #2 (the whole-cane scale) was busy 67 percent of the time. Utilization factors for the crane and hoist unloaders were 0.46 and 0.56, respectively and, with this configuration, the factory yard system was again able to service all arriving cane transport units within the normal daily operating time of 700 minutes. In addition, at no time during the day did the number of units in the system exceed nine.

6.3. Results from the Field Operations Simulation Model

The activities involved in the field operations system as modelled are discussed in section 4.3 and the flow process of the operations are illustrated in Figures 4.1 and 4.4. A computer simulation model of the

Table 6.5. Output from model FACYARD for configuration with 2 weigh queues and 2 scales (simulation time = 700 minutes).

STATISTICS FOR VARIABLES BASED ON OBSERVATION

VARIABLE	MEAN	STD. DEV.	CV	MIN	MAX	OBS	TIME IN
TISYS	9.61	4.24	0.44	3.85	24.00	236	System
TIQ2	1.82	2.96	1.63	0.00	11.75	95	Scale #1 queue
TIQ3	1.15	2.07	1.81	0.00	10.32	95	Crane queue
TIQ4	0.37	0.75	2.00	0.00	3.15	143	Hoist queue
TIQ5	3.10	3.75	1.21	0.00	14.90	144	Scale #2 queue

STATISTICS FOR TIME PERSISTENT VARIABLES

VARIABLE	MEAN	STD. DEV.	MIN	MAX	CUR. VALUE	NAME
XISYS	3.28	1.93	0.00	4.00	3.00	No. in system
BUS2	0.45	0.50	0.00	1.00	0.00	Scale #1
BUS3	0.46	0.50	0.00	1.00	1.00	Crane unloader
BUS4	0.56	0.50	0.00	1.00	1.00	Hoist unloader
BUS5	0.67	0.47	0.00	1.00	0.00	Scale #2

ENTRIES IN FILE STORAGE AREA (SERVICE QUEUES)

VARIABLE	MEAN	STD. DEV.	MAX	CUR. NO.	NAME
Q1	4.16	1.08	6.00	4.0	Future events
Q2	0.25	0.65	4.0	0.0	Scale #1 queue
Q3	0.16	0.42	2.0	0.0	Crane queue
Q4	0.08	0.28	2.0	1.0	Hoist queue
Q5	0.64	1.05	6.0	0.0	Scale #2 queue

system was developed (in GASP IV simulation language) and validated using an equipment combination of 10 wagons, 1 harvester, 2 field tractors and 2 road tractors. The model was then used to simulate operation of the system with 7 other field equipment combinations.

6.3.1. Validation of Model FIELDOP

In order to verify the model, values obtained from the simulation (with the equipment combination of 10 wagons, 1 harvester, 2 field tractors and 2 road tractors) for selected system performance indicators were compared with values actually observed in the field for a similar set of equipment. The output from program FIELDOP for this simulation is shown in Table 6.6, and the comparison of simulated and observed values is given in Table 6.7.

To further validate the model, one of the key system performance indicators, round-trip time, was subjected to the non-parametric Wilcoxon-Mann-Whitney Rank Sum test to ascertain whether the simulated and observed values for this indicator had the same statistical distribution. The test was conducted in accordance with the method given by Steel and Torrie, 1980. The details are as follows:

1. The values for both the observed and simulated samples of data for round-trip time were ranked together in ascending order.

2. The ranks of the values from the smaller sample were then added to give a total, T.

3. The rank sum T^1 that would be obtained if the values had been ranked in descending order was then calculated according to the equation $T^1 = n_1 (n_1 + n_2 + 1) - T$; where n_1 and n_2 are the number of values in the smaller and larger sample, respectively.

Table 6.6. Output from model FIELDOP for 10:1:2:2: equipment combination

NDAY	1		2		3		4		5		6		DAILY
NSHF	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	MEAN
ATRPT	117.8	113.4	115.1	110.6	107.7	125.4	117.3	122.6	141.2	153.0	117.4	101.9	120.2
TIQE	70.1	65.4	58.2	72.2	56.7	66.5	54.3	69.9	71.4	58.7	61.1	59.0	63.6
TIQF	25.6	22.1	19.8	26.2	19.5	17.1	21.3	22.7	18.7	18.9	21.6	23.8	21.5
UHT	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.41
UFT1	0.6	0.6	0.7	0.6	0.6	0.6	0.5	0.5	0.6	0.5	0.5	0.5	0.57
UFT2	0.4	0.4	0.4	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.4	0.3	0.36
URT1	0.7	0.9	1.0	0.9	0.8	1.0	1.0	0.8	0.8	0.9	1.0	0.3	0.89
URT2	0.9	0.9	1.0	0.9	0.9	1.0	0.9	0.9	1.0	0.9	0.9	1.0	0.93
TRPTS	4	3	5	3	4	4	3	3	3	3	4	4	8
TRPIT	1	0	1	0	2	0	1	0	1	0	1	0	1.1
NEWG	6	7	6	8	4	8	6	7	6	8	7	8	7
NFWG	2	3	2	2	2	2	2	3	2	2	1	2	2
TONNESD	40	30	50	30	40	40	30	30	30	30	40	40	70

NDAY = Day number
NSHF = Name of shift
ATRPT = Average trip time
TIQE = Time in empty wagon queue
TIQF = Time in full wagon queue
UHT = Utilization of harvester
UFT1 = Utilization of field tractor #1
UFT2 = Utilization of field tractor #2
TRPTS = Total number trips
TRPIT = Trips in transit at end of shift
NEWG = Number of empty wagons
NFWG = Number of full wagons
TONNESD = Tonnes of cane delivered
URTI = Utilization of road tractor #1
URT2 = Utilization of road tractor #2
A.M., P.M. = Morning, evening shift

Table 6.7. Comparison of observed and simulated values of selected system performance indicators for field operations.

Performance Indicator	Observed[1]	Simulated[1]	% Difference
Number of trips completed per day[2]	7	8	14.3
Average round-trip time	109.8	120.2	9.5
Utilization factor for harvester	0.45	0.41	9.8
Utilization factor for field tractor #1	0.65	0.57	12.3
Utilization factor for field tractor #2	0.44	0.36	18.2
Utilization factor for road tractor #1	0.80	0.89	11.3
Utilization factor for road tractor #2	0.81	0.93	14.9

[1]Average of 6 consecutive days or the equivalent of one week's operation.

[2]One trip = 2 wagons = 10 tonnes of cane (nominal capacity).

4. The rank sum T^1 for the smaller sample was then compared with tabulated values at appropriate probability levels.

The null hypothesis and the alternative tested were as follows:

H_o: Observed and simulated values of round-trip times for cane transport units over a distance of 3 kilometers between field and factory have the same distribution.

H_1: The observed and simulated valued of round-trip times have different distributions.

The data used for the test was as follows:

Simulated: (n_1 = 12)

95.4; 98.3; 97.1; 103.6; 96.7; 110.4; 102.3; 106.6; 125.6; 101.4;

93.7; 138.5.

Observed: (n_2 = 15)

105.4; 96.9; 81.1; 113.6; 142.1; 99.5; 111.3; 97.2; 91.1; 104.5;

109.7; 93.6; 125.9; 117.8; 112.0.

Ranked data: O = observed; S = simulated.

81.1(1);	91.1(2);	93.6(3);	93.7(4);	95.4(5);	96.7(6);	96.9(7);
O	O	O	S	S	S	O
97.1(8);	97.2(9);	98.3(10);	99.5(11);	101.4(12);	102.3(13);	
S	O	S	O	S	S	
103.6(14);	104.5(15);	105.4(16);	106.6(17);	109.7(18);		
S	O	O	S	O		
110.4(19);	111.3(20);	112.0(21);	113.6(22);	117.8(23);		
S	O	O	O	O		
125.6(24);	125.9(25);	138.5(26);	142.1(27)			
S	O	S	O			

$$T = 4 + 5 + 6 + 8 + 10 + 12 + 13 + 14 + 17 + 19 + 24 + 26$$

$$= 158$$

$$T^1 = 12(12 + 15 + 1) - 158$$

$$= 178$$

$$\left.\begin{array}{l} T_{0.05} = 127 \\ T_{0.01} = 115 \end{array}\right\}$$ Source: Table A.19 Steel and Torrie (1980), p. 614.

Based on the above test results, the null hypothesis H_o was accepted and it was concluded that the observed and simulated values of round-trip times for cane transport units were similarly distributed.

6.3.2 Output from FIELDOP for Different Equipment Combinations

Following validation of the field operations model, seven different field equipment combinations (see Table 6.8) were simulated for travel distances between the field and factory of 3, 5 and 7 kilometers, and for transport unit factory yard residence times of 73.98 minutes and 9.0 minutes. These two times represented the mean factory residence times obtained from program FACYARD for yard configurations having one weigh scale and two weigh scales, respectively. The results of the simulations are presented graphically in Figures 6.1 through 6.6. In the discussion that follows (and on the figures) each equipment combination is identified by four numbers which sequentially represent the numbers of wagons, harvesters, field tractors and road tractors assigned to a particular operation. For example, the notation 10 : 1 : 1 : 2 indicates an equipment combination consisting of 10 wagons, 1 harvester, 1 field tractor and 2 road tractors.

Figure 6.1 shows daily cane delivery plotted against the number of wagons assigned to the field system, for two different factory yard

Table 6.8. Equipment combinations simulated for field operations.

Wagons	Harvesters	Field Tractors	Road Tractors
8	1	1	2
10	1	1	2
12	1	1	2
14	1	1	2
8	1	2	2
10	1	2	2
12	1	2	2
14	1	2	2

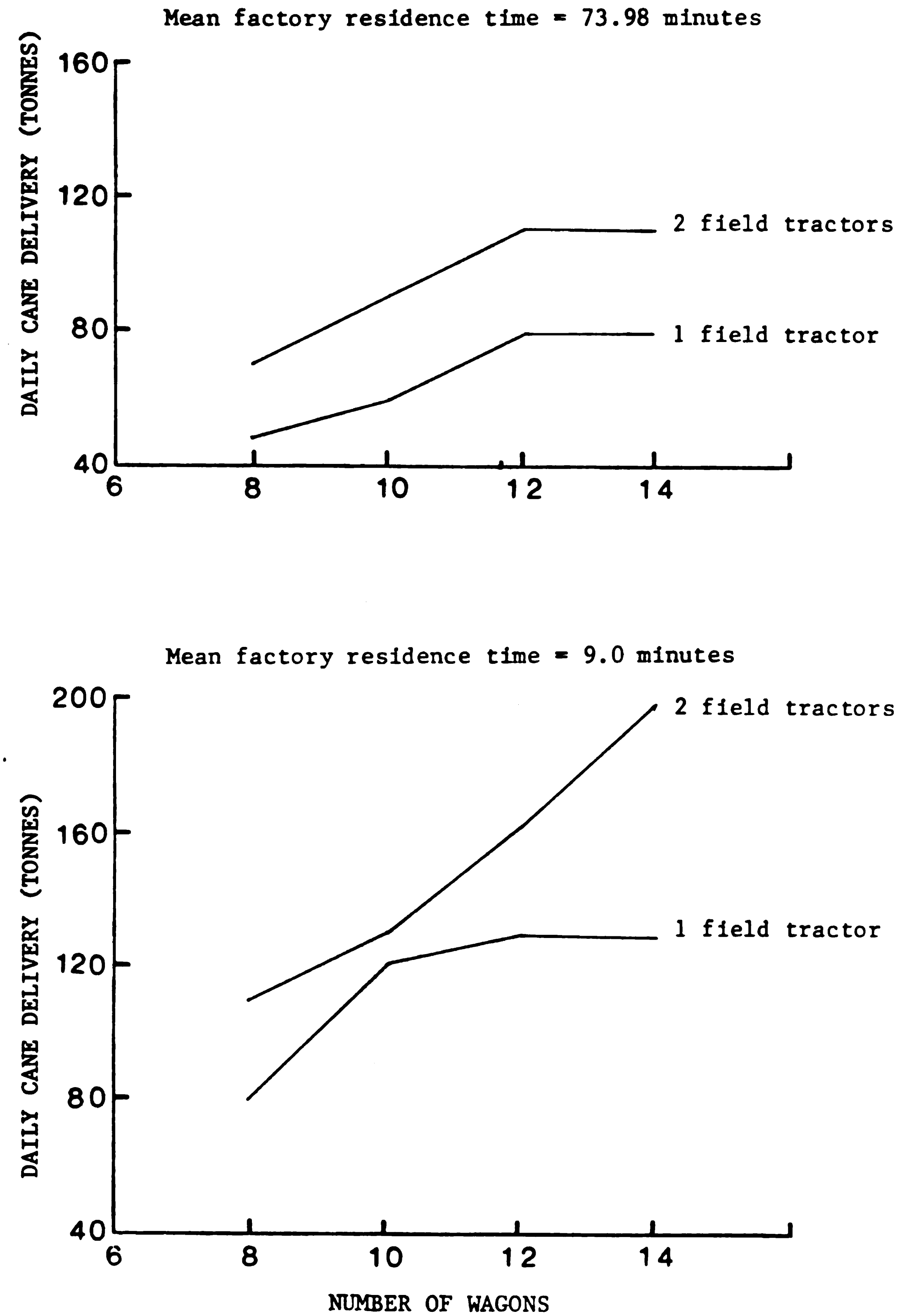


Figure 6.1 Simulated daily cane delivery vs. number of wagons in system

residence times. Generally, cane delivery increased as the number of wagons increased and outfits with two field tractors delivered 10 to 28 percent more cane than those with one field tractor. For the shorter factory yard residence time, increasing the number of wagons caused a large increase in the daily cane delivery to the factory. Systems with less than 10 wagons show a disproportionately lower output than systems with 10 or more wagons.

Figures 6.2 and 6.3 show daily cane delivery versus travel distance between the field and the factory. Indications are that:

1. Generally, the amount of cane delivered per day decreased as the travel distance increased, and the decrease became more pronounced as the distance got beyond 5 kilometers and the number of wagons became less than ten.

2. For a mean factory yard retention time of 9 minutes, the amount of cane delivered by systems with 2 field tractors and 12 or more wagons was unaffected by increases in travel distance until a distance of 5 kilometers was exceeded.

The affect of travel distance on harvester utilization is presented in Figures 6.4 and 6.5. These graphs are somewhat similar in trend to those obtained when cane delivery was plotted against travel distance. The following observations were made:

1. Harvester utilization decreased as travel distance increased.

2. For the mean transport unit factory residence time of 74 minutes, harvester utilization varied from 52 percent (with a 14 : 1 : 2 : 2 equipment combination) to 38 percent, with a 8 : 1 : 2 : 2 combination.

3. Where the mean factory yard residence time was 9 minutes, harvester utilization varied from 78 to 71 percent when two field tractors were used, and from 65 to 50 percent when one field tractor was used.

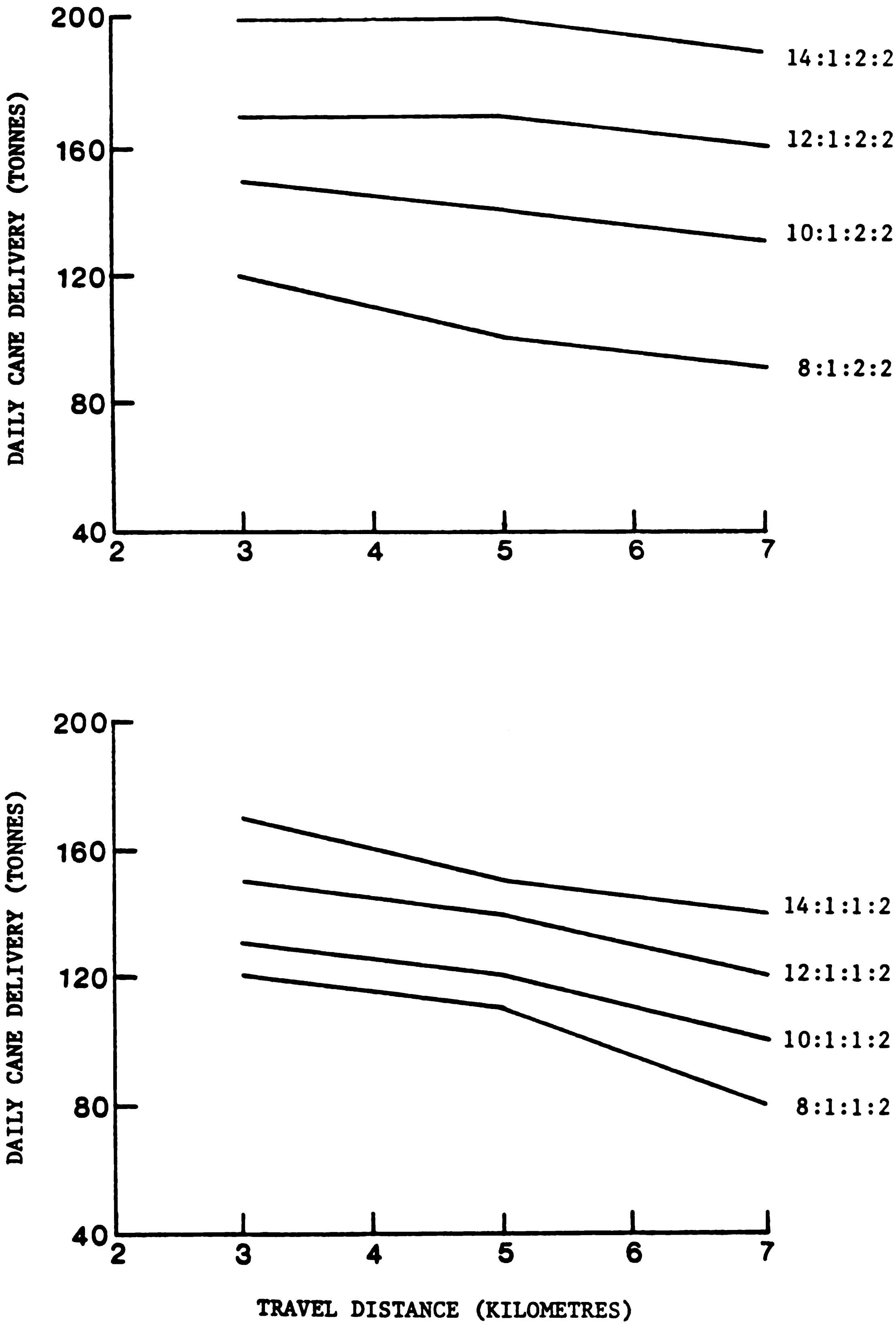
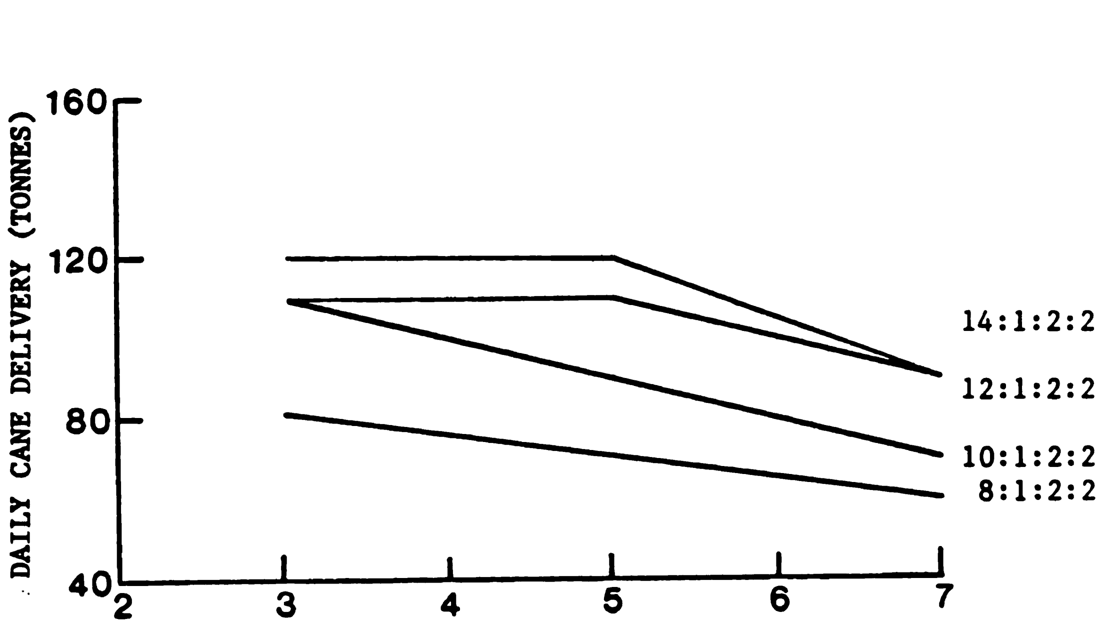


Figure 6.2 Simulated daily cane delivery vs. travel distance to factory for mean factory residence time of 9.0 minutes



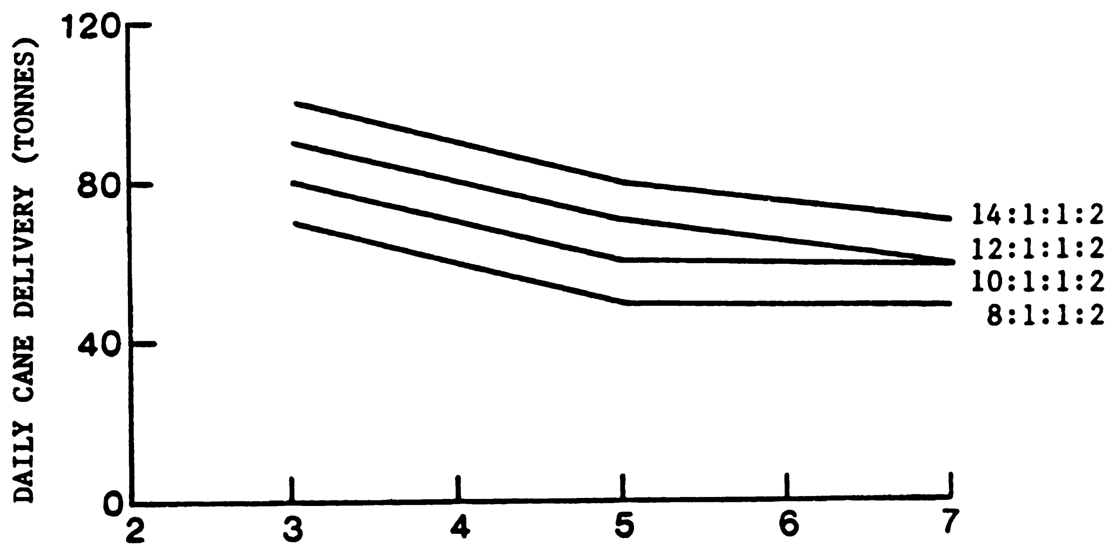


Figure 6.3 Simulated daily cane delivery vs. travel distance to factory for mean factory residence time of 73.98 minutes.

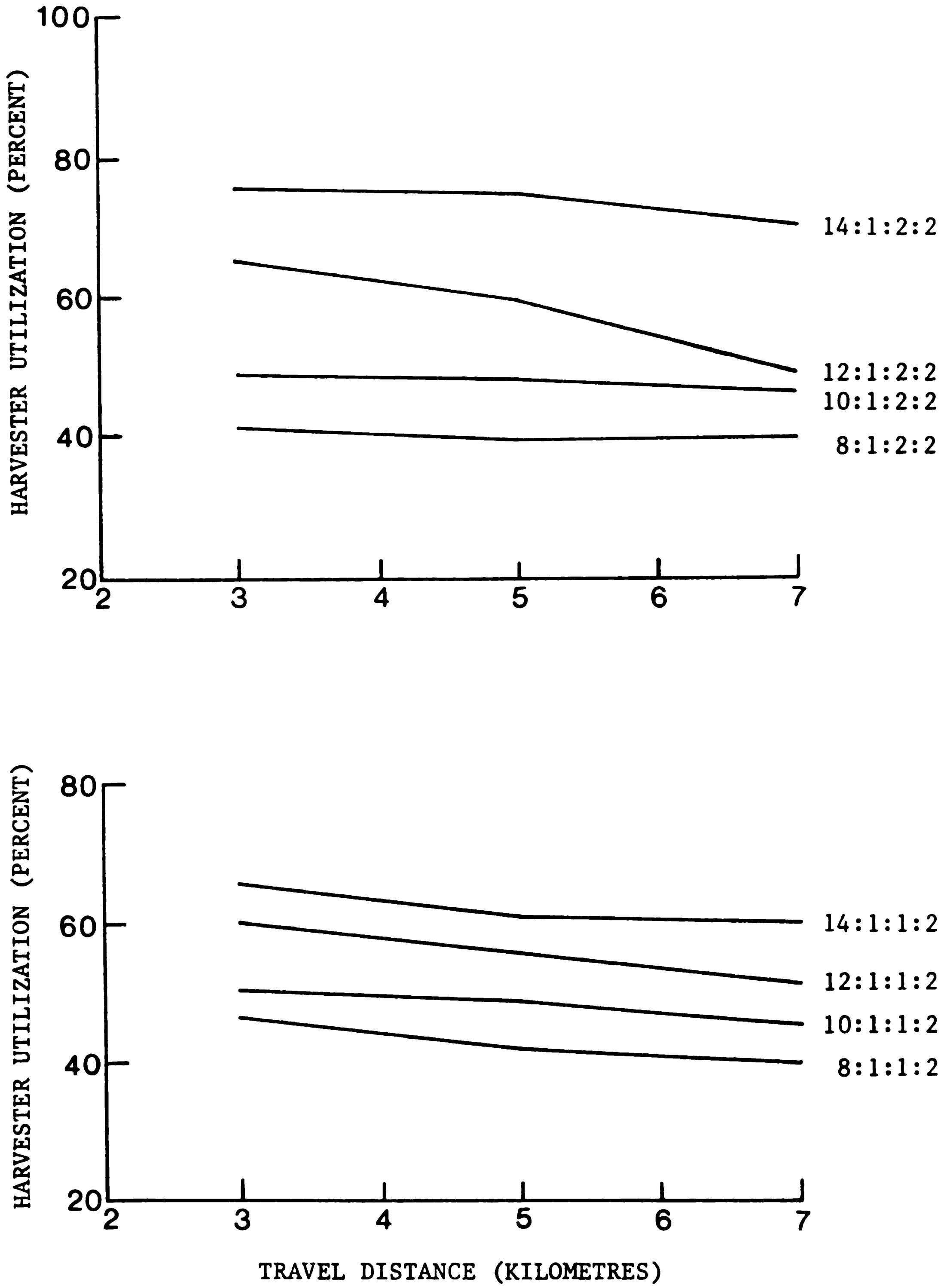


Figure 6.4 Harvester utilization vs. travel distance to factory for mean factory residence time of 9.0 minutes

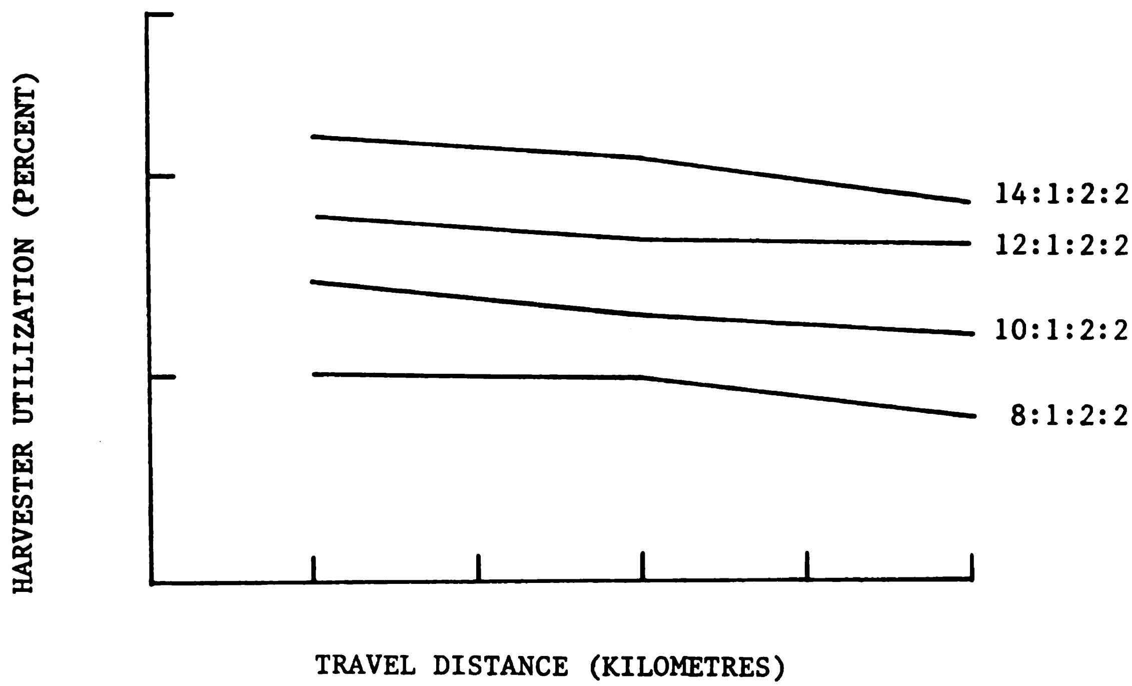


Figure 6.5 Harvester utilization vs. travel distance to factory for mean factory residence time of 73.98 minutes

Road tractor utilization versus travel distance is shown in Table 6.6. The graphs reveal that for a mean transport unit factory residence time of 74 minutes, all field equipment combinations resulted in high levels of utilization (90 - 100%) for both road tractors. Conversely, for the smaller factory residence time of 9 minutes, road tractor utilization tended to vary with the amount of cane delivered to the factory. Equipment combinations with one field tractor recorded 20 to 25 percent lower road tractor utilization than those with two field tractors.

The high level of road tractor utilization recorded for the factory yard configuration with one weigh scale reflect the fact that, with this set up, a transport unit spent an average of 65 minutes in the scale queue awaiting the weighing service (see Table 6.1) during which time the road tractor, though non-productive, was in effect busy.

6.4 General Discussion

The results presented above indicate that an increase in the total number of cane transport units serviced by the factory yard system can be achieved by either extending the daily cane receiving period or adding a second weighing facility to the system. There are a number of implications associated with either policy.

6.4.1 Implications of an Extended Work Period

An extension of the daily cane receiving period at the factory would necessitate an equivalent extension of the daily work period for field operations. This implies harvesting and transportation of cane

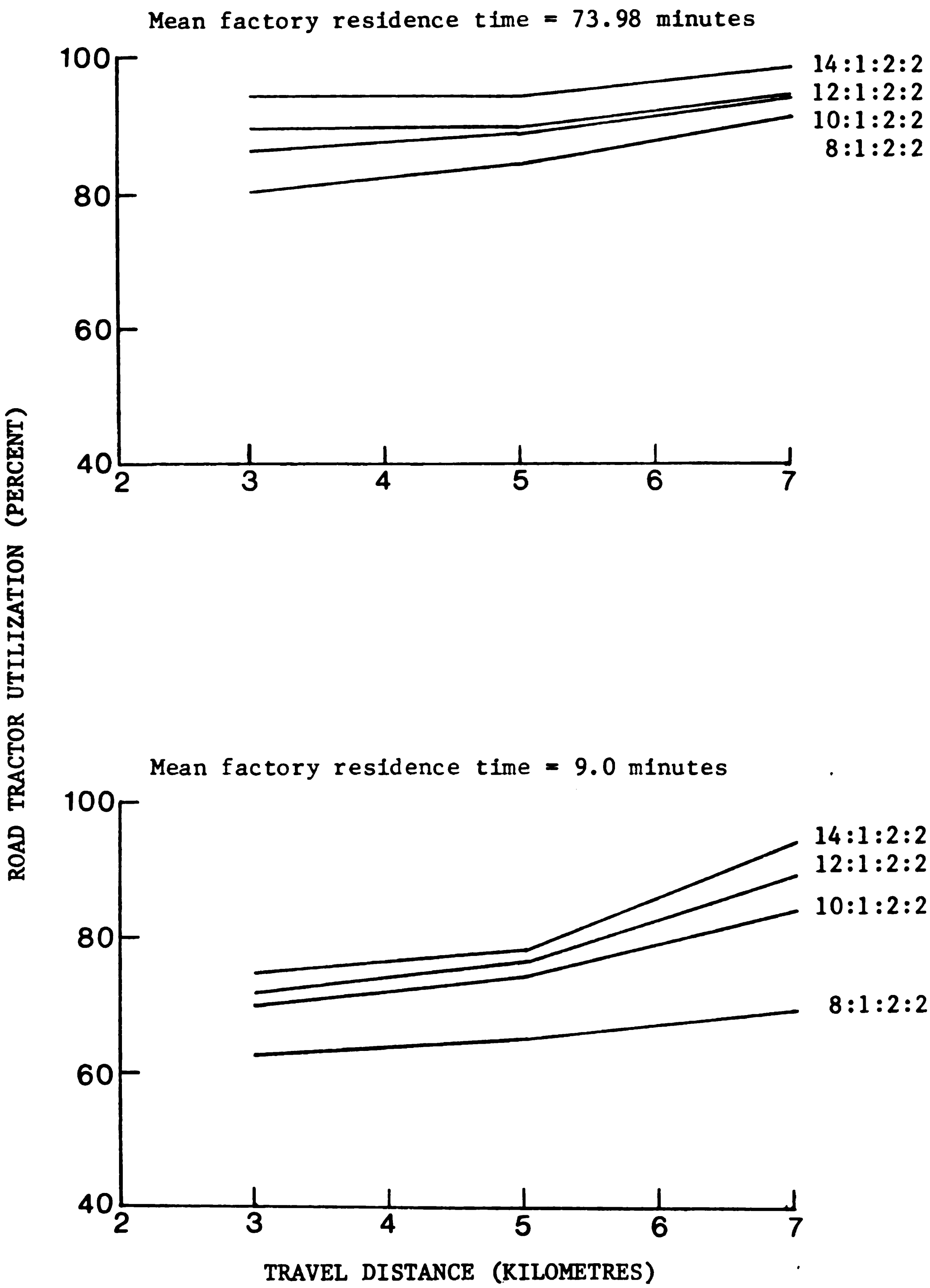


Figure 6.6 Road tractor utilization vs. travel distance to factory

during night-time hours, a change likely to be strongly opposed by workers and their trade union representatives. If accepted, the extension would bring about an immediate and significant increase in costs to the sugar industry, in the form of 'over-time' wages. Eventually, however, this increase should be offset by a contraction in the overall length of the cane harvesting season.

Sugar factories in Barbados normally grind cane continuously throughout the day for six consecutive days before shutting down for cleaning and maintenance. With a rated grinding capacity of 90 tonnes per hour, Carrington Factory requires a minimum of 2,160 tonnes of cane per day to avoid losing milling time due to lack of cane. Given the current factory yard configuration of one weigh scale and an 11 1/2 hour work period, a maximum of 210 transport units can be handled in a normal work day. With a nominal transport unit capacity of 10 tonnes, this works out to a daily cane delivery of 2,100 tonnes, 60 tonnes short of the minimum requirement, and the factory is likely to lose an average of one hour per day due to lack of cane (see Table 6.1). When the work period is extended to 16 hours a day, however, a total of 289 transport units can be processed at the factory yard (Table 6.3) making an additional 790 tonnes of cane available to the mill and eliminating mill lost time due to "grinding out".

If only chopped-cane transport units were received during the work extension period, a minimum of 29 additional transport units would be unloaded at the factory, yielding an increase in daily cane delivery of 290 tonnes, which would also be enough to eliminate mill lost time due to lack of cane.

With the current arrival frequencies of cane transport units at the factory and a single weighing facility, extension of the daily work period is unlikely to have any positive effect on the efficiency of utilization of the mechanical harvesting equipment in the field. In fact, a comparison of Tables 6.1 and 6.3 reveals that the mean factory yard residence for transport units actually increased from 73.98 to 82.83 minutes when the work period was extended.

6.4.2 Implications Associated with Two-Scale Configurations

The results presented in Tables 6.4 and 6.5 indicate that if either of the two-scale configurations were implemented, the factory yard system would be able to handle all the cane transport units currently dispatched to it within the normal daily work period. Furthermore, since the utilization factors for the service facilities (scales and unloaders) were all less than 0.65, it is evident that, with two scales, the factory yard system would be able to handle considerably more units than its current allocation.

The existing factory yard layout provides only 30 metres between the scale and the unloaders for queuing of transport units leaving the scale. This restricts unloader queue lengths to two transport units and often causes a back-up of weighed units on to the scale platform, resulting in stoppages of the weighing process and increased traffic congestion in the yard. The current queue positions also encroach on the area to the north end of the feeder table, which should be used for stacking whole cane.

With two scales in operation, this problem is likely to be accentuated since transport units will be coming out of the weighing process at about twice the current rate. The solution to the problem lies in appropriate location of the second scale, together with re-routing of the factory yard traffic and/or relocation of some of the existing factory yard facilities. Two alternative proposals aimed at achieving this are presented in the following section.

6.4.3 Proposals for Re-organization of Carrington Factory Yard

Figure 6.7 shows a plan of the current layout of Carrington Factory Yard and the path of cane transport units through the yard. Arriving units travel along the western and southern borders of the general factory area and enter the factory yard at its south end through gateway A-A. They then continue through a narrow section (10 metres) of paved yard on to the weigh scale located near the north end of the work shop building and, on leaving the scale, make a tight S-turn to get under the boom of the crane or hoist unloader.

One proposed re-organization of the factory yard is presented in Figure 6.8. Specific recommendations are as follows:

1. Remove the existing scale and relocate it, along with the second scale to form a 2-scale parallel facility, at a point B adjacent to the south border of the factory area as shown.

2. Let chopped-cane transport units, on leaving either scale, proceed along the path shown through gateway A-A and on to the crane unloader.

3. Let whole-cane units, on leaving the scale area, travel behind the office and workshop buildings along the path indicated to the hoist unloader.

4. Let empty transport units to be tared travel around the main factory building back to the scale area as shown. As is currently done, units to be tared should be given priority at the scales.

If adopted, the above proposal would provide more than enough space for queues to be formed at all service facilities and would significantly

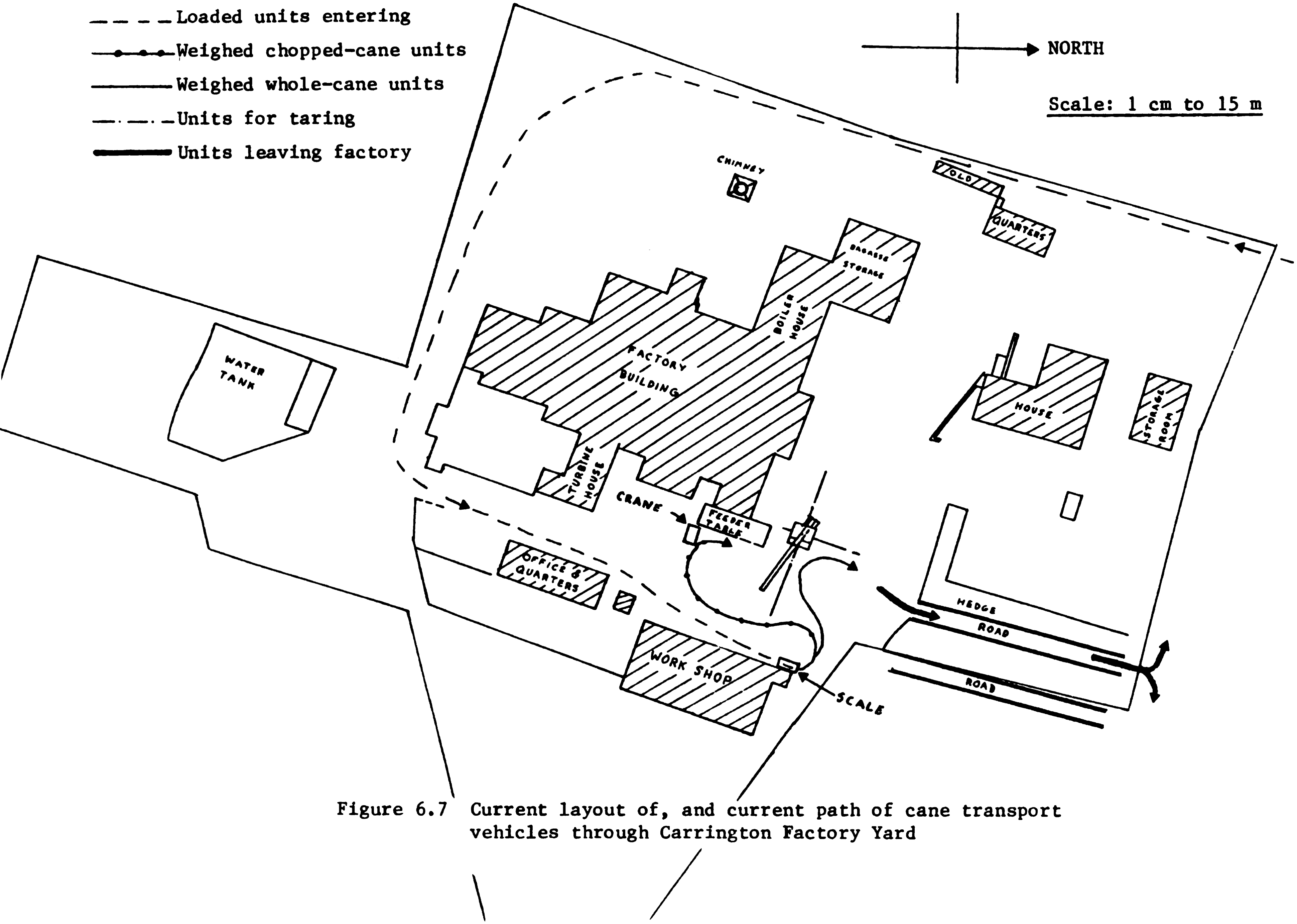


Figure 6.7 Current layout of, and current path of cane transport vehicles through Carrington Factory Yard

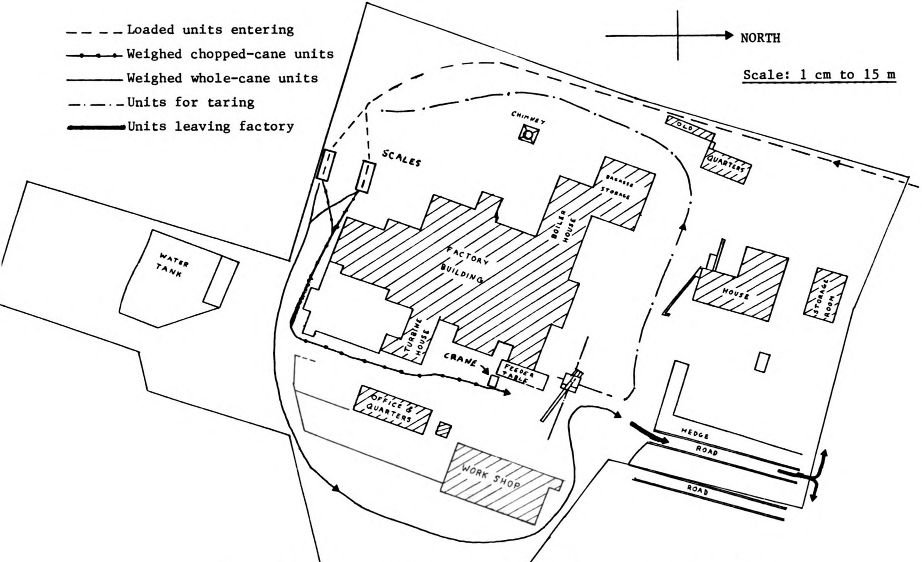


Figure 6.8 Proposal #1 for re-organization of Carrington Factory Yard

reduce traffic congestion in the central area of the factory yard. Implementation of recommendation #3 above would necessitate construction of a new road passing behind the office and workshop buildings. This should be a paved road 12-15 metres in width. A gravel surface bound with coal tar or other low-cost bituminous material should be adequate.

Proposal two, presented in Figure 6.9, is an attempt to avoid having to relocate the existing weigh scale. The recommendations are as follows:

1. Locate the additional scale (scale #2) along the southern border of the factory area as in the previous proposal.

2. Separate arrivals into two queues, one for chopped-cane transport units and one for whole-cane units.

3. Weigh chopped-cane units at scale #2 and allow them to proceed, via gateway A-A, to the crane unloader.

4. Let whole-cane units by-pass scale #2 and proceed to scale #1 via a new road passing behind the office and workshop buildings. These units will now make their final approach to the scale in a direction opposing that of the current approach (i.e., from north to south).

If adopted, proposal two would increase the yard area available for stacking whole cane (as would proposal one) and would provide additional queuing space for chopped-cane transport units. However, the area available for formation of the queue to the whole-cane hoist will remain virtually unchanged and some backing up of weighed vehicles on to scale #1 may still occur, particularly if there is a break in operation of the hoist.

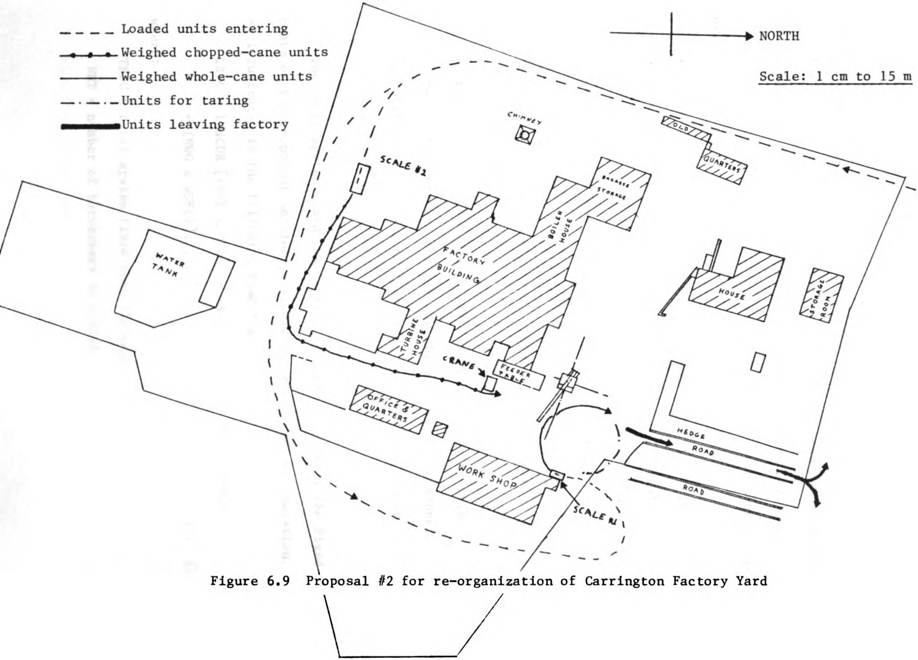


Figure 6.9 Proposal #2 for re-organization of Carrington Factory Yard

6.5 Economic Analysis

6.5.1. Calculation of Harvesting Machinery Costs

The cost of mechanical harvesting of sugar cane can be calculated on the basis of the standard machinery cost accounting methods outlined in the Agricultural Engineers Yearbook (ASAE, 1982). Component machinery costs are defined as follows:

1. Fixed costs: Costs which do not depend directly on the amount of machine use, such as depreciation, interest on investment, taxes, insurance and storage, and which are charged regardless of the extent of machine use.
2. Operating costs: Costs which depend directly on the amount of machine use; namely, repairs, maintenance, fuel and oil.
3. Labour costs: Costs which are directly associated with machinery operators and any auxillary operating personnel.
4. Total cost: The sum of the fixed, operating and labour costs.

The total system fixed cost (TSFC) is given by summing the fixed costs of the component machines involved in the harvesting operation, as illustrated in the following equation:

$$TSFC = 1/HCDR \left[(NHT \times HTFC) + (NFT \times FTFC) + (NRT \times RTFC) + (NWG \times WGFC)\right] \quad (1)$$

where:

TSFC = total system fixed cost ($/tonne)

NHT = number of harvesters in system

NFT = number of field tractors in system

NRT = number of road tractors in system

NWG = number of wagons in system

HCDR = hourly cane delivery rate from system (tonnes/hr)

HTFC = harvester fixed cost per hour

FTFC = field tractor fixed cost per hour

RTFC = road tractor fixed cost per hour

WGFC = wagon fixed cost per hour

The total system operating cost is given by:

TSOC = 1/HCDR [(UHT x HTOC) + FTOC (UFT1 + UFT2)

+ RTOC (URT1 + URT2) + (NWG x WGOC)]. . . . . (2)

where:

UHT = utilization factor for the harvester

UFT1 = utilization factor for field tractor #1

UFT2 = utilization factor for field tractor #2

URT1 = utilization factor for road tractor #1

URT2 = utilization factor for road tractor #2

HTOC = harvester operating cost per hour ($/hr)

FTOC = field tractor operating cost per hour ($/hr)

RTOC = road tractor operating cost per hour ($/hr)

TSOC = total system operating cost ($/tonne)

Total system labour cost is given by equation (3) as follows:

TSLC = [(NHT x HTLC) + (NFT x FTLC) + (NRT x RTLC)]. . . . . . (3)

where:

TSLC = total system labour cost ($/tonne)

HTLC = harvester labour cost ($/hr)

FTLC = field tractor labour cost ($/hr)

RTLC = road tractor labour cost ($/hr)

The above equations formed the basis of a Fortran program which computed the component and total costs for the eight field equipment combinations simulated. The cost structure assumed for these computations is presented in Table 6.9. Costs are based on 1982 figures and equipment utilization factors were obtained from the simulation results previously presented in Figures 6.1 through 6.6. Output from the cost program includes the total system cost per tonne and the total amount of cane harvested per year for each equipment combination. In general, the cost per tonne decreases as annual output increases. The details are shown in Tables 6.10 through 6.13. The least cost combination consists of 2 field tractors, 14 wagons and 2 scales at the factory.

6.5.2. Sensitivity of System Cost and Output to Various System Parameters

The response of cost per tonne and annual cane delivery to successive increments of two in the number of wagons is shown in Table 6.14. In all cases, incrementing the number of wagons by two resulted in a decrease in the cost per tonne and an increase in the annual cane delivery. In addition, the response to the last increment (from 12 to 14 wagons) was smaller than the responses generated by the first two increments. Generally, however, the response was neither linear nor uniform.

Table 6.15 shows the response of cost per tonne of cane harvested to the addition of a second field tractor or weigh scale to the system, and Table 6.16 shows the effect of these changes on annual cane delivery from the field system. The figures indicate that the addition of a second

Table 6.9. Machinery specifications and cost structure assumed for combine harvesting of sugar cane based on 1982 figures. (Bds. 1 dollar = U.S. 0.5 dollar).

	HARVESTER	FIELD TRACTOR	ROAD TRACTOR	CANE WAGON
MACHINE SPECIFICATIONS				
Rated capacity	25 tonnes/hr	56 kw	74 kw	5 tonnes
Fuel consumption (litres/hr)	44	14	18	
Length of harvesting season - 16 weeks with 6 working days of 10 hrs. (hours)	960	960	960	960
Estimated machine life (years)	6	8	8	10
Initial purchase price ($ Bds.)	450,000	48,000	62,000	8,000
FIXED COSTS				
Depreciation (straight line method) (salvage value of zero assumed) ($/year)	75,000	6,000	7,750	800
Interest @ 7% on written down value	18,375	1,890	2,441	308
Insurance & shelter @ 3% written down value	7,875	810	1,046	132
Total annual fixed costs	101,250	8,700	11,237	1,240
TOTAL FIXED COSTS/HR.	105.47	9.06	11.71	1.29

Table 6.9. Cont'd.

	HARVESTER	FIELD TRACTOR	ROAD TRACTOR	CANE WAGON
OPERATING COSTS				
Fuel @ $0.92 per litre ($ Bds./hr)	40.48	5.52	9.20	--
Oil @ $2.88 per litre ($/hr)	2.25	0.35	0.43	--
Repair and maintenance (10% initial cost over estimated life) ($/hr)	78.12	6.25	8.07	0.83
TOTAL OPERATING COSTS/HR	120.85	12.12	17.70	0.83
LABOUR COSTS				
Operator's wages	8.33	5.81	5.81	--
Auxillary operating personnel (2 per harvester @ $2.87/hr)	5.74	--	--	--
Mechanic's labour	4 hours/day for 96 days + 10 days @ 8 hrs/day post harvest overhaul at $4.82/hr spread over 960 day crop period 2.33	0.56	1 hour/day for 96 days + 2 days @ 8 hrs/day post harvest overhaul ⟶ 112 hrs @ $4.82 spread over 960 days 0.56	

Table 6.10. Estimated cost of combine harvesting of cane for a field system with 2 field tractors. (One factory yard scale)

Variable	No. of Wagons 8	10	12	14
	TRAVEL DISTANCE = 3 km			
System fixed cost/tonne	22.48	19.99	13.54	13.76
System operating cost/tonne	13.09	12.51	8.79	9.49
System labour cost/tonne	5.59	4.89	3.26	3.26
TOTAL SYSTEM COST/TONNE	41.16	37.39	25.59	26.51
CANE DELIVERY (TONNES/YEAR)	6720	7680	11520	11520
	TRAVEL DISTANCE = 5 km			
System fixed cost/tonne	26.22	22.84	14.77	13.76
System operating cost/tonne	15.58	14.02	9.72	9.65
System labour cost/tonne	6.52	5.59	3.56	3.26
TOTAL SYSTEM COST/TONNE	48.32	42.45	28.05	26.67
CANE DELIVERY (TONNES/YEAR)	5760	6720	10560	11520
	TRAVEL DISTANCE = 7 km			
System fixed cost/tonne	26.22	22.84	18.05	18.34
System operating cost/tonne	14.67	13.88	11.60	12.04
System labour cost/tonne	6.52	5.59	4.35	4.35
TOTAL SYSTEM COST/TONNE	47.41	42.32	34.00	34.73
CANE DELIVERY (TONNES/YEAR)	5760	6720	8640	8640

Table 6.11. Estimated cost of combine harvesting of cane for a field system with 1 field tractor. (One factory yard scale)

Variable	No. of Wagons 8	10	12	14
	TRAVEL DISTANCE = 3 km			
System fixed cost/tonne	21.18	18.86	17.05	15.60
System operating cost/tonne	12.07	11.91	11.13	10.55
System labour cost/tonne	5.59	4.89	4.35	3.91
TOTAL SYSTEM COST/TONNE	38.84	35.66	32.53	30.06
CANE DELIVERY (TONNES/YEAR)	6720	7680	8640	9600
	TRAVEL DISTANCE = 5 km			
System fixed cost/tonne	29.65	25.14	21.92	19.50
System operating cost/tonne	16.07	14.07	12.86	12.38
System labour cost/tonne	7.83	6.62	5.59	4.89
TOTAL SYSTEM COST/TONNE	53.55	45.73	40.38	36.77
CANE DELIVERY (TONNES/YEAR)	4800	5760	6720	7680
	TRAVEL DISTANCE = 7 km			
System fixed cost/tonne	29.65	30.17	25.57	22.29
System operating cost/tonne	15.34	16.63	14.10	12.77
System labour cost/tonne	7.83	7.83	6.52	5.59
TOTAL SYSTEM COST/TONNE	52.82	54.62	46.19	40.65
CANE DELIVERY (TONNES/YEAR)	4800	4800	5760	6720

Table 6.12. Estimated cost of combine harvesting of cane for a field system with 2 field tractors. (Two factory yard scales)

Variable	No. of Wagons 8	10	12	14
TRAVEL DISTANCE = 3 km				
System fixed cost/tonne	13.11	10.66	9.56	8.25
System operating cost/tonne	7.07	6.51	7.21	7.04
System labour cost/tonne	3.26	2.61	2.30	1.96
TOTAL SYSTEM COST/TONNE	23.44	19.78	19.07	17.25
CANE DELIVERY (TONNES/YEAR)	11520	14400	16320	19200
TRAVEL DISTANCE = 5 km				
System fixed cost/tonne	15.73	11.42	9.56	8.25
System operating cost/tonne	8.55	6.76	6.75	6.97
System labour cost/tonne	3.91	2.80	2.30	1.96
TOTAL SYSTEM COST/TONNE	28.19	20.98	18.61	17.15
CANE DELIVERY (TONNES/YEAR)	9600	13440	16320	19200
TRAVEL DISTANCE = 7 km				
System fixed cost/tonne	17.48	12.30	10.16	8.69
System operating cost/tonne	9.49	7.39	6.58	7.28
System labour cost/tonne	4.35	3.01	2.45	2.06
TOTAL SYSTEM COST/TONNE	31.32	22.70	19.18	18.03
CANE DELIVERY (TONNES/YEAR)	8640	12480	15360	18240

Table 6.13. Estimated cost of combine harvesting of cane for a field system with 1 field tractor. (Two factory yard scales)

Variable	No. of Wagons 8	10	12	14
TRAVEL DISTANCE = 3 km				
System fixed cost/tonne	12.36	11.60	10.23	9.18
System operating cost/tonne	7.19	7.17	7.68	7.31
System labour cost/tonne	3.26	3.01	2.61	2.30
TOTAL SYSTEM COST/TONNE	22.81	21.78	20.52	18.79
CANE DELIVERY (TONNES/YEAR)	11520	12480	14400	16320
TRAVEL DISTANCE = 5 km				
System fixed cost/tonne	13.48	12.57	10.96	10.40
System operating cost/tonne	7.70	7.88	7.76	7.98
System labour cost/tonne	3.56	3.26	2.80	2.61
TOTAL SYSTEM COST/TONNE	24.74	23.71	21.52	20.99
CANE DELIVERY (TONNES/YEAR)	10560	11520	13440	14400
TRAVEL DISTANCE = 7 km				
System fixed cost/tonne	18.53	15.09	12.79	11.14
System operating cost/tonne	10.40	9.16	8.85	8.67
System labour cost/tonne	4.89	3.91	3.26	2.80
TOTAL SYSTEM COST/TONNE	33.82	28.16	24.90	22.61
CANE DELIVERY (TONNES/YEAR)	7680	9600	11520	13440

Table 6.14. Response of total system cost/tonne and total annual output to changes in the number of wagons.

Number of Wagons	Cost per tonne	Percent change	Annual output (tonnes/year)	Percent change
		TWO FIELD TRACTORS, ONE WEIGH SCALE		
8	48.32		5760	
10	42.45	-12.15	6720	16.67
12	28.05	-33.92	10560	57.14
14	26.67	- 4.92	11520	9.09
		ONE FIELD TRACTOR, ONE WEIGH SCALE		
8	53.55		4800	
10	45.73	-14.60	5760	20.00
12	40.38	-11.70	6720	16.67
14	36.77	- 8.94	7680	14.29
		TWO FIELD TRACTORS, TWO WEIGH SCALES		
8	28.19		9600	
10	20.98	-25.58	13440	40.00
12	18.61	-11.30	16320	21.43
14	17.18	- 7.68	19200	17.65
		ONE FIELD TRACTOR, TWO WEIGH SCALES		
8	24.74		10560	
10	23.71	- 4.16	11520	9.09
12	21.52	- 9.24	13440	16.67
14	20.99	- 2.46	14400	7.14

Table 6.15. Response of cost per tonne of cane harvested to an additional field tractor or factory scale.

	PERCENTAGE CHANGE IN COST/TONNE DUE TO:	
No. of Wagons	Additional field tractor	Additional factory scale
8	- 9.77	-41.68
10	- 7.17	-50.58
12	-30.53	-33.65
14	-27.47	-35.58

Table 6.16. Response of annual cane delivery from the field system to an additional field tractor or factory scale.

	PERCENTAGE CHANGE IN ANNUAL CANE DELIVERY DUE TO:	
No. of Wagons	Additional field tractor	Additional factory scale
8	20.0	66.0
10	14.3	100.0
12	57.0	55.0
14	50.0	67.0

scale to the factory results in a much larger decrease in the cost per tonne, and a much larger increase in annual cane delivery, than does the addition of a second field tractor to the field system.

6.6. The Projected Requirement of Cane Combine Harvesters

6.6.1. The Theoretical Minimum Harvester Requirement

Approximately 18,700 hectares of sugar cane are grown annually in Barbados of which 10,400 hectares, cultivated on slopes of 10° or less, are considered suitable for combine harvesting (McGregor et al., 1979). At an average yield of 57.5 tonnes per hectare, this gives a total of 598,000 tonnes of cane, or 56 percent of the total crop, that can potentially be harvested by combines.

Since the annual rainy season extends from May to December, it is desirable to complete all cane harvesting operations during the 16 week period, January 1st to April 30th. On the basis of a 10 hour work day and a 6 day work week, this makes a total of 960 hours theoretically available for harvesting. It is acknowledged that, even in the dry season, some work days will be rained out. However, in the absence of historical data on "suitable days for field work", one is forced to work with the theoretical figure.

On the basis of 100 observations made during the 1982 harvesting season, the average time taken for a chopper harvester to fill a cane wagon under Barbadian conditions is 11.98 minutes. Given a nominal wagon capacity of 5 tonnes (computed from weigh scale data) this works out to a theoretical cane harvesting rate of 25 tonnes per hour or 250 tonnes per day. Putting all these figures together, the theoretical amount of cane that can be harvested annually by a single machine is 24,000 tonnes. Therefore, to harvest the entire 10,400 hectares considered suitable for combine harvesting, a theoretical minimum of 25 harvesters would be required.

6.6.2. Required Number of Harvesters for Various Simulated Annual Output Levels

Table 6.17 shows simulated hourly cane delivery rates for various field equipment combinations, transporting cane over a distance of 5 kilometres between field and factory. Also shown are the minimum numbers of harvesters required at each level of output to ensure complete harvesting of the 10,400 hectares considered suitable for combine harvesting. The figures reveal that, for any given field equipment combination, significant reductions in the number of combine harvesters required can be achieved by either adding a second field tractor, or a second factory yard scale, or both.

Some of the better combine harvester operators each harvested approximately 7,000 tonnes of cane during the 1982 season (Personal Communication). This represents a very modest harvesting rate of 7.3 tonnes per hour. Table 6.15 reveals several equipment combinations that could result in significant improvements on this performance, the best arrangement being one with 2 field tractors, 14 wagons and 2 weigh scales at the factory yard.

Table 6.17. Cane delivery rates and the number of harvesters required for various equipment combinations. (Travel distance = 5 km)

No. of Wagons	Harvesting rate tonnes per hour	Cane delivered tonnes per annum	No. of harvesters required
	1 FIELD TRACTOR, 1 WEIGH SCALE		
8	5	4800	124
10	6	5760	104
12	7	6720	89
14	8	7680	78
	2 FIELD TRACTORS, 1 WEIGH SCALE		
8	6	5760	104
10	7	6720	89
12	11	10520	57
14	12	11520	52
	1 FIELD TRACTOR, 2 WEIGH SCALES		
8	11	10560	57
10	12	11520	52
12	14	13440	45
14	15	14400	41
	2 FIELD TRACTORS, 2 WEIGH SCALES		
8	10	9600	62
10	14	13440	45
12	17	16320	37
14	20	19200	31

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

1. On the basis of the close agreement between observed and simulated values of selected system performance indicators, it is concluded that the computer simulation models FIELDOP and FACYARD accurately reflected the operational characteristics of the field and factory yard systems, respectively.
2. The main bottleneck of the harvesting system is the weighing operation at the factory. Given the inter-arrival data used in this study, factory yard systems having only one weigh scale are incapable of handling all of the cane transport units dispatched to them in a normal work day.
3. Extension of the daily work period from 11½ hours to 16 hours (700 to 960 minutes) would increase the utilization efficiency of combine harvesters only if cane reception at the factory were restricted to mechanically harvested cane during the period of extension.
4. The addition of a second weigh scale to the factory yard system can result in an 88 percent reduction in the average time spent by a cane transport unit in the yard.
5. With two scales in operation, the factory yard system would be able to process all of the transport units currently dispatched to it, without excessive buildup of service queues.

6. In terms of efficiency of utilization of service facilities in the factory yard, there is no significant difference between having a single transport unit arrival queue supplying two scales, and having a separate queue for each scale.
7. The introduction of a second weighing facility at the factory can have a profound effect on field systems from which the factory receives cane. With two scales in operation, a 50-60 percent increase in combine harvester utilization can be achieved and the overall output from the field system can be increased by up to 68 percent.
8. With two scales at the factory, field system output can be increased by increasing the number of wagons assigned to the system until either the throughput capacity of the harvester becomes limiting, or the daily cane quota allocated to the field system is satisfied.
9. Field systems having only one field tractor per harvester can be expected to deliver 15-25 percent less cane per day than field systems having two field tractors per harvester.
10. As a single measure, the installation of a second weigh scale at those factories having only one scale will generate the most significant reduction in combine harvesting costs, and the most significant increase in the total amount of cane harvested annually by a harvester.

7.2. Recommendations

Based on the results of this study, the following are recommended:

1. Installation of a second weigh scale at the factory yard in accordance

with the guidelines suggested in section 6.4.3., so as to avoid excessive congestion of the central area of the yard.

2. Assignment of two field tractors to a combine harvester in all cases.

3. An increase in the number of cane transport wagons assigned to a harvester from the traditional 8 to 12 or even 14.

7.3. Suggestions for Further Work

Due to the unavailability of reliable data on the frequency and duration of mechanical breakdowns, a fixed time loss of one hour per day was assumed for repairs, while designing the models. Modification of the models to represent breakdown frequency and duration as stochastic processes may, therefore, be a valuable improvement.

Use of the models to simulate cane transportation systems using wagons having larger carrying capacities (10 or 15 tonnes rather than 5) may also be useful, since the reduction in the number of trips between the field and the factory may be significant.

Finally, from the factory standpoint, it would be interesting to use the models to investigate the feasibility of temporarily storing combine harvested cane (probably in pits) for subsequent elevation on to the feeder table of the factory. The current practice of unloading combine harvested cane directly on to the feeder table prolongs the residence time of cane transport units at the factory yard.

APPENDICES

APPENDIX I

DATA COLLECTION MANUAL

DATA COLLECTION MANUAL FOR MONITORS

A. Materials Required

1. Clip board.
2. Data collection sheets.
3. Scoring pencils/ball-point pens.
4. Digital watch.

B. Data Collection Procedures

I. Getting Ready

1. Pick up 10 sheets of the correct form for the task to which you are assigned, and clip them to your clip board.

2. Fill in the headings on each sheet.

   For example: -

   Location: Asbhury, Field #1

   Start time: Time of arriving on scene and taking up observation position.

   Page of Pages

   Put the number 1 in the first blank space on the first page and leave the second space blank.

   Whenever you go to a new page, be sure to fill in the first blank space with the appropriate page number.

   Monitor: Print your name here.

   Date: Fill in the appropriate date: e.g., Tues. Feb. 2.

II. Taking Data

3. Station yourself at the position suggested.
4. You will be recording times of more than one event and events may happen very close together. Get the time first and worry about the vehicle description later.
5. Record the time for each event by noting the EXACT TIME that the event occurs.
6. DO NOT TOUCH ANY OF THE BUTTONS ON THE DIGITAL WATCH!
7. Simply keep looking at your watch while keeping an eye on what is going on, and write down the exact time that the event occurs in the appropriate column on the data sheet.

   For Example:

Start Hook	Start Load	Start Load
095706	100230	102255

   The events are described on the last page of this manual.
8. Record the vehicle description and number of trailers/ wagons in the spaces provided on the data sheet.
9. Observation No. 2 begins when the second vehicle undergoes the FIRST EVENT on your data sheet.
10. Add your comments of any happenings which are not normal.

    For example: - Collisions, flat tyres, extra movements to unblock roads, arguments between tractor operators and field or factory personnel, machine breakdowns or other abnormal stoppages.

You can obtain reasons for stoppages. If a stoppage occurs and the reason is not immediately obvious to you, ask the field or factory supervisor, machine operators or even maintenance personnel what the problem is. These people have been informed about the project and about your tasks and are expecting you to ask questions.

Comments refer to a time value to show that it is abnormal.

For example: - The end of unloading is later than normal because an argument broke out between the driver and the unloader operator. To indicate this, we need a comment number made up of the observation number and the column number.

11. Place the comment number at the end of the line in the comments column and write the comment in the space provided at the bottom of the data sheet.

12. Some typical data collection is attached. Note that only one set of headings should be on each page or set of pages.

13. On the first day of work, we will not undertake any data recording. Instead, we will tour the fields and factories so that you can become familiar with operating procedures and learn about the machinery. You will be able to observe each type of machine closely and you should feel free to ask as many questions as you like.

14. On the second day, we will start recording observations but this will only be a practice run. We will spend 30 minutes to 1 hour at each location and you will be shown exactly how to record the required observations. Each of you will get a change not only to do some practice recording for your own tasks, but also to see what the tasks of your co-workers involve.
15. From the third day, you will be on your own. I shall, however, be coming around from time to time to make sure that everything goes as planned.
16. Finally, a word of caution. Please make sure that you do not get involved in arguments or other unfriendly discussions with field or factory personnel, with machinery operators or members of the public who may be on the scene. The people are doing us a favour by accommodating us on their properties and we should, therefore, be as polite as possible.

C. <u>Identification of Events</u>

<u>Vehicle Description</u>

1. Type: tractor or truck.
2. Identification: licence plate number.
3. No. of trailer.

I. Events in Field

ARRIVE FIELD	Time at which tractor returning from factory stops to unhook empty trailers.
START HOOK	Time at which infield tractor stops in front of empty trailer to hook it up.

END LOAD	Time at which rear wheels of full trailer pass harvester delivery chute, or loader.
END UNHOOK	Time at which field tractor moves after depositing trailer.
DEPART FIELD	Time at which tractor plus two full trailers leave field for factory.

II. Events at Factory

ARRIVE FACTORY	Time at which tractor and two full trailers stop in queue at factory, or when front wheels of tractor enter factory gate.
DEPART FACTORY	Time at which tractor and two empty trailers leave factory or pass monitor at factory exit gate.
START WEIGH	Time at which first trailer or truck stops moving on weigh scale.
END WEIGH	Time at which rear wheels of second trailer or truck leave the weigh scale.
START UNLOAD	Time at which truck or first trailer stops in position for unloading.
END UNLOAD	Time at which truck or tractor and two empty trailers leave unloading area.

APPENDIX II

FORTRAN LISTING OF
DATA ANALYSIS PROGRAM
"DATANAL"

```
 09/13/82  MSU HUSTLER 2      LSD 51.45  09/10/82  CYBER750
.11.35.09.IB75603
.11.35.09.JOB READ-  09/13/82 .11.34.19.
.11.35.09.HARVEY,RG2,JC500,L100.
.11.35.10.LAST ACCESS- B 13.49 08/15/82
.11.35.10.RUNS- 0C48    PN DOLLAR BALANCE $00107.55
.11.35.10.000501     CARDS READ  VALUE  $0000000.40
.11.35.10.CP-PP SEC.      .000-      .000  $      .00
.11.35.10.DISPOSE,*OUTPUT,PRINTER=PAGE,FORMAT=ELIT
.11.35.10.E.1SIDED.
.11.35.10.RP  00000006  000000000247  MAXFL 025100
.11.35.10.CP-PP SEC.      .008-      .332  $      .01
.11.35.10.FTN.
.11.35.33.      1.159 CP SECONDS COMPILATION TIME
.11.35.33 RP  00000300  000000013236  MAXFL 052000
.11.35.33.CP-PP SEC.    1.171-    27.628  $      .97
.11.35.33.HAL.
.11.35.33.ZZZZMPL - CYCLE 01. HAL 5. MPL
.11.35.33.FILE ATTACHED
.11.35.34.HAL 5.139
.11.35.34.ZZZZSOO - CYCLE 01. HAL 5. SPL
.11.35.34.FILE ATTACHED
.11.35.34.RP  00000331  000000013625  MAXFL 025400
.11.35.34.CP-PP SEC.    1.214-    28.592  $     1.01
.11.35.34.EXEC,HALEXEC.
.11.35.34.LDSET,LIB=ZZZZSOO.
.11.35.34.LGO.
.11.35.40.EXEC BEGUN.11.35.40.
.11.35.41.     STOP
.11.35.42.     032300    FINAL EXECUTION FL.
.11.35.42.      0.862 CP SECONDS EXECUTION TIME.
.11.35.42.MAX FILES 0007 MAX PRUS 000100B.
.11.35.42.RP  00000474  000000014467  MAXFL 050000
.11.35.42. PP     30.810 SEC.
.11.35.42.CP USE     2.317 SEC    VALUE$     .45
.11.35.42.PP USE    38.055 SEC    VALUE$     .10
.11.35.42.CM USE     4.102 W-H    VALUE$     .97
.11.35.42.TOTAL COMPUTE VALUE AT RG2 $     1.52
```

```
C****                 MAIN PROGRAM DATANAL
C
C      TO FIT A 3-PARAMETRE GAMMA DISTRIBUTION TO WORK TIMES
C**** USING THE SIMPLEX MAMIMUM LIKELIHOOD METHOD
C**** REFERENCE--AUDSLEY,E AND D.S. BOYCE, J. AGR. ENG. RES. 18:217-230
C****            'EXACT SOLUTIONS FOR CYCLIC TRANSPORT SYSTEMS'
C
      PROGRAM DATANAL (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      REAL P(5,9),V(5)
      INTEGER FMT(10),UNITS(5)
      COMMON /BLK1/NV,X(1000),NTS,NACT(15),IGO,IPAGE
      COMMON /BLK2/VALU(100,20),DIFF(100,20),UNITS
      READ(5,1) IGO,NUMB,NACT
      IF(NUMB.EQ.0) STOP
      IPAGE=1
      NTS=1
      IF(IGO)25,25,40
C**** GO TO REDUCE RAW DATA TO ANALYZABLE FORM
   25 CALL DACON(NUMB)
      GO TO 45
C**** IF NON-RAW DATA READ IN NUMBER,UNITS OF DATA AND FORMAT
   40 READ(5,2) NV,UNITS,FMT
C**** READ IN DATA ACCORDING TO FORMAT (FMT)
      READ(5,FMT) (X(I),I=1,NV)
   45 WRITE(6,11)NACT,IPAGE,NV,UNITS
      IPAGE=IPAGE+1
      NV1=NV-1
      DO 50 I=1,NV1
      M=NV-I
C**** SORT VALUES INTO ASCENDING ORDER
      DO 50 J=1,M
      K=J+1
      IF(X(K).GE.X(J)) GO TO 50
      DUM=X(K)
      X(K)=X(J)
      X(J)=DUM
   50 CONTINUE
C**** LIST SORTED (RANKED) VALUES
      WRITE(6,12) (X(I),I=1,NV)
C**** ZERO ARRAYS FOR P AND V MATRICES
   30 DO 35 I=1,5
      V(I)=0.0
      DO 35 J=1,9
      P(I,J)=0.0
   35 CONTINUE
C**** INITIALIZE MAXIMUM LIKELIHOOD MATRIX
      DO 55 J=1,4
      P(1,J)=3.0
      P(2,J)=1.0
      P(3,J)=X(1)-10.0
   55 P(J,J)=1.273*P(J,J)
C**** CALL THE SIMPLEX SUBROUTINE
      CALL SIMPLE(3,4,P,V,L)
C**** CALL THE FITTING SUBROUTINE
      CALL FITA(P,L)
      NTS=NTS+1
C**** IF ANOTHER SET OF NON-RAW DATA, READ FROM NEXT SET
   98 IF(IGO.GT.0.AND.NTS.LE.NUMB) GO TO 40
C****
C**** IF MORE COLUMNS OF RAW DATA TO CHECK, RETURN TO SUBROUTINE
C**** DACON
      IF(IGO.LE.0.AND.NTS.LE.NUMB) GO TO 25
    1 FORMAT(2I5,15A4)
    2 FORMAT(I5,5A4,10A4)
   11 FORMAT(1H1,15A4,T65,"PAGE..",I2/1H0,"NUMBER OF VALUES = ",
     1I4,T30,"UNITS =",5A4)
   12 FORMAT(1H0,"VALUES IN ASCENDING ORDER..."//(1X,9F8.3))
      STOP
      END
```

```
C****
C****
      SUBROUTINE FITA(P,L)
C****
      DIMENSION P(5,9)
      COMMON /BLK1/NV,X(1000),NTS,NACT(15),IGO,IPAGE
      COMMON /BLK2/VALU(100,20),DIFF(100,20),UNITS
      COMMON /BLK3/NYVALU(50),BUNDRY(50),THNO(50)
      ET=P(1,L)
      PL=P(2,L)
      EPS=P(3,L)
      DO 9 I=1,50
      BUNDRY(I)=0.0
      NYVALU(I)=0.0
    9 THNO(I)=0.0
      NO=20
      NB=NO+1
      BUNDRY(1)=IFIX(X(1)-0.5)
      BUNDRY(NB)=IFIX(X(NV)+1.0)
C**** FIND CLASS BOUNDARIES
      SIZE=(BUNDRY(NB)-BUNDRY(1))/NO
      DO 3 I=2,NB
      J=I-1
    3 BUNDRY(I)=BUNDRY(J)+SIZE
      J=0
      I=2
    4 J=J+1
      IF(J.GT.NV) GO TO 1
      IF(X(J).GE.BUNDRY(I)) GO TO 5
      NYVALU(I-1)=NYVALU(I-1)+1
      GO TO 4
    5 I=I+1
      IF(I.GT.NB) GO TO 2
      J=J-1
      GO TO 4
    2 NYVALU(NO)=NYVALU(NO)+NV-J+1
    1 CONTINUE
C**** FIND THEORETICAL NUMBER IN CLASSES
      CONST=(PL**ET)/GAMMA(ET)
      DO 6 I=1,NO
      J=I+1
      A=BUNDRY(I)-EPS
      B=BUNDRY(J)-EPS
      C=(A+B)/2.0
      THNO(I)=CONST*NV*SIZE*(RINT(A,PL,ET)+RINT(B,PL,ET)+4.0*
     1RINT(C,PL,ET))/6.0
    6 CONTINUE
      WRITE(6,200)
  200 FORMAT(1H1/1H0,5X,"LOWER BOUND.",3X,"UPPER BOUND.",5X,
     1"ACTUAL NUMBER.",5X,"THEORETICAL NUMBER."/)
      DO 7 I=1,NO
      J=I+1
      WRITE(6,201)BUNDRY(I),BUNDRY(J),NYVALU(I),THNO(I)
  201 FORMAT(1H ,5X,F7.2,8X,F7.2,13X,I4,16X,F7.2)
    7 CONTINUE
C**** FIND CHI SQUARED
      CHI2=0.0
      IDF=0
      DO 8 I=1,NO
      DI=THNO(I)-NYVALU(I)
      IF(THNO(I).LT.1.0) GO TO 8
      CHI2=CHI2+(DI*DI)/THNO(I)
      IDF=IDF+1
    8 CONTINUE
      IDF=IDF-4
      WRITE(6,202) IDF,CHI2
  202 FORMAT(1H0/1H0,5X,"VALUE OF CHI SQUARED FOR",I3,2X,
     1"DEGREES OF FREEDOM =",F10.4/)
      IPAGE=IPAGE+1
      CALL GRAPH(NO)
      RETURN
      END
```

```
C****
C****
      FUNCTION RINT(X,PL,ET)
C****
      IF(X.LE.0.0) GO TO 1
      RINT=EXP((ET-1.0)*ALOG(X)-PL*X)
      RETURN
    1 RINT=0.0
      RETURN
      END
```

```
C****
C****
C**** PLOT ACTUAL AND THEORETICAL HISTOGRAM
      SUBROUTINE GRAPH(NO)
C****
      INTEGER UNITS(5)
      COMMON /BLK1/NV,X(1000),NTS,NACT(15),IGO,IPAGE
      COMMON /BLK2/VALU(100,20),DIFF(100,20),UNITS
      COMMON /BLK3/NYVALU(50),BUNDRY(50),THNO(50)
      DIMENSION ALINE(80)
      DATA DOT,BLANK,AYE,TEA/".",",","A","T"/
      BIG=NYVALU(1)
      DO 9 I=2,NO
      IF(NYVALU(I).LE.BIG) GO TO 10
      BIG=NYVALU(I)
   10 IF(THNO(I).LE.BIG) GO TO 9
      BIG=THNO(I)
    9 CONTINUE
      FACT=BIG/60.0
      DO 1 L=10,70,10
    1 ALINE(L)=(L-10)*FACT
      WRITE(6,200)NACT,IPAGE,UNITS, (ALINE(L),L=10,70,10)
  200 FORMAT(1H1,15A4,T65,"PAGE..",I2/
     11H0,"HISTOGRAM OF ACTUAL AND THEORETICAL NUMBERS IN CLASS.....",
     25A4/1H0,5X,7(F6.2,4X))
      DO 2 L=1,80
    2 ALINE(L)=DOT
      WRITE(6,201)  (ALINE(L),L=11,71,10)
  201 FORMAT(1H ,8X,7(A1,9X))
      WRITE(6,202)  (ALINE(L),L=11,80)
  202 FORMAT(1H ,8X,70A1)
      DO 3 I=1,NO
      J=I+1
      DO 4 L=10,80
    4 ALINE(L)=BLANK
      ALINE(80)=DOT
      MHA=IFIX(NYVALU(I)/FACT+11.5)
      MHT=IFIX(THNO(I)/FACT+11.5)
      IF(MHT.GT.80) MHT=80
      IF(MHA.GT.80) MHA=80
      DO 5 L=11,MHA
    5 ALINE(L)=AYE
      ALINE(11)=DOT
      WRITE(6,203) BUNDRY(I), (ALINE(L),L=11,80)
  203 FORMAT(1H ,1X,F7.2,70A1)
      DO 6 L=11,MHA
    6 ALINE(L)=BLANK
      DO 7 L=11,MHT
    7 ALINE(L)=TEA
      ALINE(11)=DOT
      WRITE(6,203) BUNDRY(J),  (ALINE(L),L=11,80)
    3 CONTINUE
      DO 8 L=10,80
    8 ALINE(L)=DOT
      WRITE(6,204)  (ALINE(L),L=11,80)
  204 FORMAT(1H ,8X,70A1/////)
      RETURN
      END
```

```
C****
C****
      SUBROUTINE SIMPLE(NP,NPS,P,VFUN,L)
C****
      COMMON /BLK1/NV,X(1000),NTS,NACT(15),IGO,IPAGE
      COMMON /BLK2/VALU(100,20),DIFF(100,20),UNITS
      COMMON /BLK3/NYVALU(50),BUNDRY(50),THNO(50)
      DIMENSION P(5,9),VFUN(5)
      REAL LIK
      INTEGER H
      A=1.1
      B=0.618034
      G=1.618034
      NP1=NPS+1
      NP2=NPS+2
      NP3=NPS+3
C**** SET INITIAL VALUES OF FUNCTION
      DO 1 J=1,NPS
    1 VFUN(J)=LIK(P,J,NP,NPS)
      WRITE(6,199)
  199 FORMAT(//," SIMPLEX ITERATIONS - (MAX 300 PRINT EACH 10TH)"/)
  198 DO 101 NT=1,300
C**** FIND MAXIMUM AND MIMIMUN VALUE...
      FB=VFUN(1)
      H=1
      FS=VFUN(1)
      L=1
      DO 2 J=2,NPS
      IF(VFUN(J).LE.FB) GO TO 3
      H=J
      FB=VFUN(H)
      GO TO 2
    3 IF(VFUN(J).GE.FS) GO TO 2
      L=J
      FS=VFUN(L)
    2 CONTINUE
C**** P(I,H) IS THE MAXIMUM POINT, P(I,L) IS THE MINIMUM
C**** FIND CENTROID P(I,NPS+1), NOT INCLUDING P(I,H)...
      DO 4 I=1,NP
      P(I,NP1)=0.0
      DO 4 J=1,NPS
      IF(J.EQ.H) GO TO 4
      P(I,NP1)=P(I,NP1)+P(I,J)/NP
    4 CONTINUE
      IF((NT-NT/10*10).NE.0) GO TO 21
      WRITE(6,200) ((P(I,J),I=1,NP),VFUN(J),J=1,NPS)
  200 FORMAT(1HO/(5X,4E15.8))
      IF(MOD(NT,90).EQ.0) GO TO 22
      GO TO 21
   22 WRITE(6,202)NACT,IPAGE
      IPAGE=IPAGE+1
  202 FORMAT(1H1,15A4,T65,"PAGE..",I2/
     11HO,"SIMPLEX ITERATIONS CONTD")
C**** REFLECT POINT P(I,H) TO THE NEW POINT P(I,NP2)...
   21 DO 5 I=1,NP
    5 P(I,NP2)=(1.0+A)*P(I,NP1)-A*P(I,H)
      VFUN1=LIK(P,NP2,NP,NPS)
C**** IS THIS NEW POINT A MINIMUM?
      IF(VFUN1.LT.VFUN(L)) GO TO 6
      DO 7 J=1,NPS
      IF(J.EQ.H) GO TO 7
      IF(VFUN1.LT.VFUN(J)) GO TO 8
    7 CONTINUE
      GO TO 9
    8 DO 10 I=1,NP
   10 P(I,H)=P(I,NP2)
      VFUN(H)=VFUN1
      GO TO 100
    6 DO 11 I=1,NP
C**** WE HAVE A NEW MINIMUM EXPAND P(I,NP2) TO P(I,NP3)...
   11 P(I,NP3)=(1.0+G)*P(I,NP2)-G*P(I,NP1)
      VFUN2=LIK(P,NP3,NP,NPS)
C**** IS P(I,NP3) A NEW MINIMUM?
      IF(VFUN2.GT.VFUN1) GO TO 8
      DO 12 I=1,NP
   12 P(I,H)=P(I,NP3)
      VFUN(H)=VFUN2
```

```
      GO TO 100
C**** IS P(I,NP2) A NEW MAXIMUM?
    9 IF(VFUN1.GT.VFUN(H)) GO TO 13
      DO 14 I=1,NP
   14 P(I,H)=P(I,NP2)
      VFUN(H)=VFUN1
   13 DO 15 I=1,NP
   15 P(I,NP3)=B*P(I,H)+(1.0-B)*P(I,NP1)
      VFUN2=LIK(P,NP3,NP,NPS)
C**** CONTRACTION OF P(I,NP3)...
C**** IS P(I,NP3) LESS THAN THE MAXIMUM?
      IF(VFUN2.LT.VFUN(H)) GO TO 16
      DO 17 I=1,NP
      DO 17 J=1,NPS
   17 P(I,J)=(P(I,J)+P(I,L))/2.0
      GO TO 100
   16 DO 18 I=1,NP
   18 P(I,H)=P(I,NP3)
      VFUN(H)=VFUN2
  100 IF((NT-NT/10*10).NE.0) GO TO 101
      SD2=0.0
      RMN=0.0
      DO 19 J=1,NPS
      RMN=RMN+P(1,J)
   19 SD2=SD2+P(1,J)*P(1,J)
      SD2=(SD2-RMN*RMN/NPS)/NPS
      RMN=RMN/NPS
      IF(SD2.GT.1.0E-5) GO TO 101
      GO TO 20
  101 CONTINUE
   20 WRITE(6,201)NACT,IPAGE,RMN,SD2,(P(I,L),I=1,NP)
  201 FORMAT(1H1,15A4,T65,"PAGE..",I2/1H0,5X,
     1"MEAN VALUE OF FUNCTION AT MINIMUM=",
     1E15.6/6X,"STANDARD DEVIATION =",E15.6/1H0,5X,"PARAMETERS",
     2" AT MINIMUM....","ALPHA(SHAPE FACTOR)",14X,"= ",E15.6/,
     331X,"LAMBDA(SCALE FACTOR) OR 1/BETA   = ",
     4E15.6/ 31X,"EPSILON(OFFSET)",18X,"= ",
     5E15.6///)
      RETURN
      END
```

```
C****
C****
      REAL FUNCTION LIK(P,NPP,NP,NPS)
C****
      DIMENSION P(5,9)
      COMMON /BLK1/NV,X(1000),NTS,NACT(15),IGO,IPAGE
      ET=P(1,NPP)
      PL=P(2,NPP)
      EP=P(3,NPP)
      IF(ET.LE.0.0.OR.ET.GT.20.0) GO TO 1
      IF(PL.LE.0.0.OR.EP.GE.X(1)) GO TO 1
      LIK=PL*SA(EP)+NV*ALOG(GAMMA(ET))-NV*ET*ALOG(PL)-(ET-1.0)*
     1SB(EP)
      RETURN
    1 LIK=10E6
      RETURN
      END
```

```
C****
C****
      FUNCTION SA(EP)
C****
      COMMON /BLK1/NC,X(1000),NTS,NACT(15),IGO,IPAGE
      SUM=0.0
      DO 1 I=1,NC
    1 SUM=SUM+(X(I)-EP)
      SA=SUM
      RETURN
      END
```

```
C****
C****
      FUNCTION SB(PL)
C****
      COMMON /BLK1/NC,X(1000),NTS,NACT(15),IGO,IPAGE
      SUM=0.0
      DO 1 I=1,NC
    1 SUM=SUM+ALOG(X(I)-PL)
      SB=SUM
      RETURN
      END
```

```
C****
C****
      SUBROUTINE DACON(NC)
C****
      DIMENSION H(20),RM(20),S(20)
      INTEGER FMT(10),UNITS(5)
      COMMON /BLK1/NR,X(1000),NTS,NACT(15),IGO,IPAGE
      COMMON /BLK2/VALU(100,20),DIFF(100,20),UNITS
C**** IF THIS IS THE SECOND CALL TO THIS SUBROUTINE DO NOT READ
C**** RAW DATA
      IF(NTS.GT.1) GO TO 45
      IF(IGO.EQ.-1) GO TO 20
      IF(IGO.EQ.-2) GO TO 21
      IF(IGO.EQ.-3) GO TO 22
   20 D=1.0
      GO TO 23
   21 D=60.0
      GO TO 23
   22 D=3600.0
   23 READ(5,2)NR,UNITS,FMT
      WRITE(6,11)NACT,IPAGE,UNITS
      WRITE(6,9)
      WRITE(6,10)
      IPAGE=IPAGE+1
C**** CONVERT RAW DATA FROM HOURS, MINUTES AND SECONDS TO
C**** DECIMAL HRS, MINS, OR SECS
      DO 40 I=1,NR
      READ (5,FMT)  (H(J),RM(J),S(J),J=1,NC)
      DO 25 K=1,NC
      VALU(I,K)=DECIHR(H(K),RM(K),S(K),D)
   25 CONTINUE
C**** LIST CONVERTED DATA IN HRS, MINS OR SECS
   30 WRITE(6,12) I, (VALU(I,KK),KK=1,NC)
      IF(MOD(I,45).EQ.0) GO TO 35
      GO TO 40
   35 WRITE(6,11)NACT,IPAGE,UNITS
      IPAGE=IPAGE+1
   40 CONTINUE
      CALL COLDIF(NC)
   45 K1=0
      DO 50 K=1,NR
      IF(DIFF(K,NTS).LE.0) GO TO 50
      K1=K1+1
      X(K1)=DIFF(K,NTS)
   50 CONTINUE
C**** SET NUMBER OF VALUES EQUAL TO NUMBER OF DIFFERENCES FOUND
      NR=K1
    2 FORMAT(I5,5A4,10A4)
   11 FORMAT(1H1,15A4,T65,"PAGE..",I2//T20,"INPUT DATA - ",5A4/)
    9 FORMAT(6X,"ARRIVE",3X,"START",5X,"END",5X,"START",5X,
     1"END")
   10 FORMAT(5X,"FACTORY",3X,"WEIGH",4X,"WEIGH",4X,"UNLOAD",
     13X,"UNLOAD"/)
   12 FORMAT(1X,I3,10(F7.1,2X))
      RETURN
      END
```

```
C****
C****
      SUBROUTINE COLDIF(NC)
C****
C**** THIS SUBROUTINE CONVERTS RAW DATA TO DIFFERENCES BETWEEN COLUMNS
      INTEGER UNITS(5)
      COMMON /BLK1/NR,X(1000),NTS,NACT(15),IGO,IPAGE
      COMMON /BLK2/VALU(100,20),DIFF(100,20),UNITS
      WRITE(6,11)NACT,IPAGE,UNITS
      WRITE(6,9)
      WRITE(6,10)
      IPAGE=IPAGE+1
      DO 45 I=1,NR
      DO 30 KK=1,NC
      IF(KK.EQ.NC) GO TO 25
      DIFF(I,KK)=VALU(I,KK+1)-VALU(I,KK)
      GO TO 30
   25 DIFF(I,KK)=VALU(I,NC)-VALU(I,1)
   30 CONTINUE
   35 WRITE(6,12) I,(DIFF(I,KJ),KJ=1,NC)
      IF(MOD(I,45).EQ.0) GO TO 40
      GO TO 45
   40 IPAGE=IPAGE+1
   41 WRITE(6,11)NACT,IPAGE,UNITS
      IPAGE=IPAGE+1
   45 CONTINUE
   11 FORMAT(1H1,15A4,T65,"PAGE..",I2//T20,"TIME DIFFERENCES - ",
     15A4//)
    9 FORMAT(8X,"WEIGH",4X,"WEIGH",4X,"UNLOAD",4X,"UNLOAD",
     14X,"FACTORY")
   10 FORMAT(8X,"QTIME",4X,"TIME",5X,"QTIME",5X,"TIME",6X,
     1"RES TIME"/)
   12 FORMAT(1X,I3,2X,F6.1,3X,F6.1,2(4X,F6.1),5X,F6.1)
      RETURN
      END
```

```
C****
C****
      FUNCTION DECIHR(A,B,C,D)
C****
      DECIHR = (A+B/60.0+C/3600.0)*D
      RETURN
      END
```

FACTORY YARD OPERATIONS - CARRINGTON FACTORY PAGE.. 1

INPUT DATA - MINUTES

	ARRIVE FACTORY	START WEIGH	END WEIGH	START UNLOAD	END UNLOAD
1	516.4	536.4	543.4	566.7	573.1
2	517.0	543.5	546.8	576.9	578.2
3	528.1	549.7	553.0	591.0	593.5
4	530.8	553.2	555.6	595.8	597.8
5	550.8	564.2	567.0	600.2	601.9
6	554.2	567.2	570.0	604.1	606.8
7	560.8	573.0	575.3	609.6	612.0
8	567.4	578.9	581.6	616.6	619.0
9	583.0	596.9	600.4	622.5	626.3
10	587.2	603.9	606.4	628.9	633.3
11	623.4	636.4	638.8	655.7	659.5
12	625.6	639.1	641.8	664.0	667.1
13	656.2	670.1	672.3	678.9	681.6
14	662.8	677.0	679.8	689.2	694.4
15	666.1	680.3	682.5	697.1	700.0
16	667.9	682.8	685.6	701.8	705.3
17	674.0	689.0	690.7	708.1	711.6
18	681.1	693.8	697.2	714.1	716.7
19	689.6	700.8	704.4	719.6	722.2
20	694.1	711.1	713.8	725.3	729.7
21	707.1	722.8	726.6	734.0	740.8
22	714.2	726.9	728.7	743.7	749.9
23	717.3	728.9	731.2	753.6	756.0
24	720.2	731.4	734.4	762.3	763.4
25	738.9	749.0	751.3	766.3	768.6
26	749.8	764.2	766.0	771.4	775.2
27	766.7	776.3	778.4	796.3	804.4
28	762.9	778.7	780.9	806.8	810.1

FACTORY YARD OPERATIONS - CARRINGTON FACTORY PAGE.. 2

TIME DIFFERENCES - MINUTES

	WEIGH QTIME	WEIGH TIME	UNLOAD QTIME	UNLOAD TIME	FACTORY RES TIME
1	20.0	7.0	23.3	6.4	56.7
2	26.5	3.2	30.2	1.3	61.2
3	21.6	3.3	38.1	2.4	65.3
4	22.4	2.4	40.2	2.0	67.0
5	13.4	2.8	33.1	1.7	51.1
6	13.1	2.7	34.2	2.7	52.7
7	12.2	2.3	34.3	2.4	51.2
8	11.6	2.7	35.0	2.5	51.7
9	14.0	3.5	22.1	3.8	43.3
10	16.8	2.5	22.6	4.3	46.1
11	13.0	2.4	16.9	3.8	36.1
12	13.5	2.7	22.2	3.0	41.5
13	13.9	2.2	6.7	2.7	25.4
14	14.3	2.8	9.3	5.2	31.7
15	14.2	2.2	14.5	2.9	33.9
16	14.9	2.8	16.3	3.4	37.4
17	15.0	1.7	17.3	3.5	37.6
18	12.7	3.4	16.9	2.6	35.6
19	11.3	3.6	15.3	2.5	32.6
20	17.0	2.7	11.5	4.4	35.5
21	15.7	3.8	7.4	6.8	33.7
22	12.7	1.8	15.1	6.2	35.8
23	11.6	2.4	22.4	2.4	38.7
24	11.2	3.0	27.9	1.1	43.2
25	10.1	2.3	15.0	2.3	29.7
26	14.4	1.8	5.4	3.8	25.4
27	9.5	2.1	18.0	8.1	37.7
28	15.8	2.3	25.9	3.2	47.2

FACTORY YARD OPERATIONS - CARRINGTON FACTORY PAGE.. 3

NUMBER OF VALUES = 28 UNITS = MINUTES

VALUES IN ASCENDING ORDER...

9.550	10.117	11.200	11.267	11.550	11.567	12.167	12.717	12.733
12.983	13.083	13.383	13.533	13.867	13.967	14.233	14.250	14.350
14.917	15.017	15.667	15.817	16.767	16.983	19.983	21.583	22.433
26.500								

SIMPLEX ITERATIONS - (MAX 300 PRINT EACH 10TH)

.43266824E+01	.39141692E+00	-.51145327E+00	.91468765E+02
.40591956E+01	.21380439E+00	-.60887934E+00	.87820716E+02
.43484037E+01	.38231145E+00	-.47336545E+00	.90040380E+02
.48227548E+01	.21478137E+00	-.52928951E+00	.92263484E+02
.43635936E+01	.30660243E+00	-.53241633E+00	.84755193E+02
.47075387E+01	.33926012E+00	-.47535705E+00	.84088528E+02
.47442150E+01	.30068875E+00	-.49975253E+00	.83563433E+02
.45539517E+01	.28238562E+00	-.52199057E+00	.84160918E+02
.14862276E+02	.10169962E+01	.90519532E+00	.74867333E+02
.15635693E+02	.11822876E+01	.10642053E+01	.74414570E+02
.95992462E+01	.67418837E+00	.19037891E+00	.76385932E+02
.17163772E+02	.13297352E+01	.13098001E+01	.74675727E+02
.15414567E+02	.11114954E+01	.10087209E+01	.74218249E+02
.15752651E+02	.11737487E+01	.10726431E+01	.74251340E+02
.16496545E+02	.12231264E+01	.11765533E+01	.74234350E+02
.15725989E+02	.11394738E+01	.10502308E+01	.74209999E+02
.15701730E+02	.11438644E+01	.10532025E+01	.74193322E+02
.15731708E+02	.11536767E+01	.10607811E+01	.74189937E+02
.15503870E+02	.11271944E+01	.10225719E+01	.74192895E+02
.15563633E+02	.11407773E+01	.10379447E+01	.74189871E+02
.15635496E+02	.11426049E+01	.10454322E+01	.74188561E+02
.15649715E+02	.11452659E+01	.10481755E+01	.74188546E+02
.15603147E+02	.11398984E+01	.10404824E+01	.74188476E+02
.15603990E+02	.11416904E+01	.10419342E+01	.74188394E+02

SIMPLEX ITERATIONS CONTD

.15658793E+02	.11573867E+01	.12101456E+01	.74174175E+02
.15550187E+02	.11596221E+01	.13511326E+01	.74162213E+02
.15524591E+02	.11393102E+01	.11141655E+01	.74178329E+02
.15653355E+02	.11529379E+01	.11143372E+01	.74182551E+02
.14043390E+02	.11409700E+01	.25164445E+01	.74067794E+02
.14802711E+02	.11267927E+01	.16424112E+01	.74107156E+02
.14963347E+02	.11501671E+01	.17007446E+01	.74111212E+02
.15334500E+02	.11627370E+01	.15826068E+01	.74143612E+02
.97586099E+01	.98819558E+00	.45487319E+01	.73687839E+02
.10507773E+02	.10301260E+01	.43532476E+01	.73739718E+02
.98961771E+01	.10096667E+01	.46190670E+01	.73736131E+02
.10993240E+02	.10361174E+01	.39678143E+01	.73763174E+02
.72424132E+01	.78369717E+00	.51211042E+01	.73457487E+02
.79924506E+01	.79539884E+00	.46632835E+01	.73432340E+02
.75937138E+01	.76758372E+00	.46402607E+01	.73537239E+02
.87343092E+01	.88178390E+00	.46318710E+01	.73471634E+02
.65929051E+01	.780245850E+00	.62986481E+01	.73009314E+02
.57124492E+01	.74465937E+00	.66904823E+01	.72975775E+02
.66035938E+01	.76561257E+00	.58235230E+01	.73160722E+02
.72995936E+01	.85246026E+00	.59030120E+01	.73245546E+02
.38227033E+01	.58110096E+00	.78601336E+01	.72408230E+02
.35744093E+01	.52852789E+00	.80185420E+01	.72252742E+02
.27523969E+01	.50537113E+00	.86514895E+01	.72490415E+02
.41717089E+01	.61925531E+00	.80303546E+01	.72420487E+02
.29993557E+01	.49289028E+00	.86133557E+01	.72036800E+02
.25865198E+01	.46493686E+00	.88594841E+01	.72063825E+02
.24021990E+01	.43229298E+00	.89942108E+01	.71981076E+02
.27156126E+01	.46082722E+00	.86446305E+01	.72069775E+02
.23376925E+01	.41265523E+00	.90171690E+01	.71955447E+02
.26081033E+01	.44890850E+00	.89190937E+01	.71965578E+02
.24474536E+01	.43322308E+00	.89658820E+01	.71962829E+02
.25582457E+01	.43840926E+00	.88786879E+01	.71960365E+02

SIMPLEX ITERATIONS CONTD

.23913111E+01	.41912101E+00	.90034461E+01	.71950334E+02
.24554715E+01	.42757346E+00	.89748134E+01	.71950622E+02
.24370836E+01	.42351829E+00	.89773193E+01	.71950510E+02
.23845442E+01	.41854316E+00	.90234252E+01	.71950021E+02
.24123606E+01	.42158479E+00	.90025036E+01	.71949798E+02
.23960191E+01	.41935178E+00	.90128466E+01	.71949842E+02
.24113725E+01	.42130245E+00	.89997214E+01	.71949806E+02
.23955260E+01	.41975256E+00	.90129986E+01	.71949813E+02
.24040959E+01	.42087970E+00	.90072285E+01	.71949772E+02
.24083011E+01	.42130741E+00	.90042429E+01	.71949769E+02
.24066431E+01	.42116280E+00	.90063419E+01	.71949771E+02
.24036444E+01	.42071019E+00	.90073917E+01	.71949770E+02

FACTORY YARD OPERATIONS - CARRINGTON FACTORY PAGE.. 6

```
MEAN VALUE OF FUNCTION AT MINIMUM=     .240655E+01
STANDARD DEVIATION =     .316780E-05

PARAMETERS AT MINIMUM....ALPHA(SHAPE FACTOR)                =     .240830E+01
                         LAMBDA(SCALE FACTOR) OR 1/BETA     =     .421307E+00
                         EPSILON(OFFSET)                    =     .900424E+01
```

LOWER BOUND.	UPPER BOUND.	ACTUAL NUMBER.	THEORETICAL NUMBER.
9.00	9.90	1	.69
9.90	10.80	1	2.14
10.80	11.70	4	3.03
11.70	12.60	1	3.34
12.60	13.50	5	3.27
13.50	14.40	6	2.97
14.40	15.30	2	2.58
15.30	16.20	2	2.16
16.20	17.10	2	1.76
17.10	18.00	0	1.41
18.00	18.90	0	1.11
18.90	19.80	0	.87
19.80	20.70	1	.67
20.70	21.60	1	.51
21.60	22.50	1	.39
22.50	23.40	0	.29
23.40	24.30	0	.22
24.30	25.20	0	.16
25.20	26.10	0	.12
26.10	27.00	1	.09

VALUE OF CHI SQUARED FOR 6 DEGREES OF FREEDOM = 9.2657

```
FACTORY YARD OPERATIONS - CARRINGTON FACTORY                     PAGE.. 7

HISTOGRAM OF ACTUAL AND THEORETICAL NUMBERS IN CLASS..... MINUTES

       0.00      1.00      2.00      3.00      4.00      5.00      6.00
        .         .         .         .         .         .         .
      .......................................................................
 9.00.AAAAAAAAAA
 9.90.TTTTTTT
 9.90.AAAAAAAAAA
10.80.TTTTTTTTTTTTTTTTTTTTT
10.80.AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
11.70.TTTTTTTTTTTTTTTTTTTTTTTTTTTTTT
11.70.AAAAAAAAAA
12.60.TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT
12.60.AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
13.50.TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT
13.50.AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
14.40.TTTTTTTTTTTTTTTTTTTTTTTTTTTTTT
14.40.AAAAAAAAAAAAAAAAAAAA
15.30.TTTTTTTTTTTTTTTTTTTTTTTTTT
15.30.AAAAAAAAAAAAAAAAAAAA
16.20.TTTTTTTTTTTTTTTTTTTTTT
16.20.AAAAAAAAAAAAAAAAAAAA
17.10.TTTTTTTTTTTTTTTTTT
17.10.
18.00.TTTTTTTTTTTTTT
18.00.
18.90.TTTTTTTTTTT
18.90.
19.80.TTTTTTTTT
19.80.AAAAAAAAAA
20.70.TTTTTTT
20.70.AAAAAAAAAA
21.60.TTTTT
21.60.AAAAAAAAAA
22.50.TTTT
22.50.
23.40.TTT
23.40.
24.30.TT
24.30.
25.20.TT
25.20.
26.10.T
26.10.AAAAAAAAAA
27.00.T
      .......................................................................
```

```
123456789.123456789.123456789.123456789.123456789.123456789.123456789.12345
123456789.123456789.123456789.123456789.123456789.12345678   IB75603   000040
123456789.123456789.123456789.123456789.123456789.12345678   IB75603   000040
```

```
.23.26.28. 09/13/82      SHEETS PRINT              44  $    1.36
.23.26.28. 09/13/82      LINES PRINT             1396
.23.26.28. 09/13/82      LINES READ              1383
.23.26.28. 09/13/82      TOTAL LINES PROCESSED   1389  $    1.11
.23.26.28. 09/13/82      COST AT RG3                   $    3.03
```

APPENDIX III

FORTRAN LISTING OF

FACTORY YARD OPERATIONS PROGRAM

"FACYARD"

```
 09/20/82  MSU HUSTLER 2       LSD 51.47  09/19/82  CYBER750
.10.37.31.IE75790
.10.37.31.JOB READ-  09/20/82 .10.37.08.
.10.37.31.HARVEY,RG2,JC1000,L100.
.10.37.31.LAST ACCESS- B 18.35 09/17/82
.10.37.31.RUNS- 0063    PN DOLLAR BALANCE $00074.45
.10.37.31.000349     CARDS READ  VALUE  $0000000.28
.10.37.32.CP-PP SEC.       .000-      .000  $      .00
.10.37.32.DISPOSE,*OUTPUT,PRINTER=PAGE,FORMAT=ELIT
.10.37.32.E,1SIDED.
.10.37.32.RP  00000006  000000000247  MAXFL 025100
.10.37.32.CP-PP SEC.       .012-      .326  $      .01
.10.37.32.HAL,GASPIV.
.10.37.33.ZZZZMPL  - CYCLE 01, HAL 5, MPL
.10.37.33.FILE ATTACHED
.10.37.33.HAL 5.140
.10.37.33.GASPIV   - CYCLE 01, HAL-GASPIV
.10.37.33.FILE ATTACHED
.10.37.33.RP  00000026  000000000635  MAXFL 025400
.10.37.33.CP-PP SEC.       .046-     1.243  $      .05
.10.37.33.LIBRARY,GASPIV.
.10.37.34.CP-PP SEC.       .047-     1.325  $      .05
.10.37.34.FTN.
.10.37.49.          .301 CP SECONDS COMPILATION TIME
.10.37.49.RP  00000244  000000007513  MAXFL 052000
.10.37.49.CP-PP SEC.       .366-    20.533  $      .55
.10.37.49.LDSET,PRESET=ZERO.
.10.37.49.LGO.
.10.37.54.EXEC BEGUN.10.37.54.
.10.37.55.      STOP
.10.37.55.      046000    FINAL EXECUTION FL.
.10.37.55.       0.295 CP SECONDS EXECUTION TIME.
.10.37.55.MAX FILES 0005 MAX PRUS 000100E.
.10.37.55.RP  0000043E  0000000103CE  MAXFL 060000
.10.37.55. PP      23.104 SEC.
.10.37.55.CP USE       .947 SEC    VALUE$      .18
.10.37.55.PP USE     32.793 SEC    VALUE$      .08
.10.37.55.CM USE      3.113 W-H    VALUE$      .74
.10.37.55.TOTAL COMPUTE VALUE AT RG2 $     1.00
```

```
C****                MAIN PROGRAM FACYARD
C
C     HANDLES FACTORY YARD OPERATIONS, WEIGHING AND UNLOADING
C****
      PROGRAM FACYARD(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
      DIMENSION NSET(4000)
      COMMON QSET(4000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/XISYS,TISYS,TIQ2,TIQ3,TIQ4,BUS2,BUS3,BUS4,XVW
      EQUIVALENCE (NSET(1),QSET(1))
C
C**** SET VALUES FOR CARD READER AND PRINTER
C
      NCRDR=5
      NPRNT=6
C
      CALL GASP
      STOP
      END
```

```
C****
C
      SUBROUTINE INTLC
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/XISYS,TISYS,TIQ2,TIQ3,TIQ4,BUS2,BUS3,BUS4,XVW
C
C**** INITIALISE LIST OF VARIABLES
C****
      XISYS=0.0
      BUS2=0.0
      BUS3=0.0
      BUS4=0.0
      XVW=0.0
      RETURN
C
      END
```

```
C****
C****
      SUBROUTINE EVNTS(IX)
C****
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/XISYS,TISYS,TIQ2,TIQ3,TIQ4,BUS2,BUS3,BUS4,XVW
C****
      IF(IX-2) 101,102,103
  101 CALL ARIVAL
      GO TO 104
  102 CALL ENDWGH
      GO TO 104
  103 CALL ENDULD
  104 RETURN
C
      END
```

```
C****
C****
C**** SUBROUTINE TO HANDLE ARRIVAL OF 2-WAGON TRAINS AT FACTORY
C
      SUBROUTINE ARIVAL
C****
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/XISYS,TISYS,TIQ2,TIQ3,TIQ4,BUS2,BUS3,BUS4,XVW
C
C**** DETERMINE TYPE OF VEHICLE FOR WEIGHING
      KJ=IFIX(ATRIB(5)+0.5)
C**** DETERMINE IF THIS IS WHOLE CANE OR CHOPPED CANE
      KL=IFIX(ATRIB(6)+0.5)
C**** SET TIME OF NEXT ARRIVAL
C
      ATRIB(1)=TNOW+ERLNG(KJ,1)
      ATRIB(2)=1.0
      ATRIB(3)=ATRIB(1)
      CALL FILEM(1)
C****
C**** ADD ONE TO NUMBER IN SYSTEM AND COLLECT STATS.
C****
      XISYS=XISYS+1.0
      CALL TIMST(XISYS,TNOW,1)
      ATRIB(3)=TNOW
C****
C**** IF SCALE NOT BUSY, GO TO SCALE AND PREDICT END OF WEIGHING
C****
      IF(BUS2) 111,104,105
  104 BUS2=1.0
      CALL TIMST(BUS2,TNOW,2)
      ATRIB(1)=TNOW+ERLNG(3,2)
      ATRIB(2)=2.0
      CALL FILEM(1)
C**** SET TIME IN Q2 AND COLLECT STATS.
      TIQ2=0.0
      CALL COLCT(TIQ2,2)
      RETURN
C****
C**** IF SCALE IS BUSY, PUT ARRIVAL IN Q2 AND RECORD TIME IN;
C****
  105 ATRIB(4)=TNOW
      CALL FILEM(2)
      RETURN
C
  111 CALL ERROR(87)
      STOP
      END
```

SUBR

```
C****
C****
C**** SUBROUTINE TO HANDLE VEHICLES AT END OF WEIGHING
C****
      SUBROUTINE ENDWGH
C****
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/XISYS,TISYS,TIQ2,TIQ3,TIQ4,BUS2,BUS3,BUS4,XVW
C****
C**** DETERMINE TYPE OF VEHICLE FOR WEIGHING
      KJ=IFIX(ATRIB(5)+0.5)
C**** DETERMINE IF THIS IS WHOLE CANE OR CHOPPED CANE
      KL=IFIX(ATRIB(6)+0.5)
C****
C**** SEND WEIGHED VEHICLE TO CHOPPED CANE CRANE OR WHOLE CANE HOIST
C****
      IF(KL.EQ.2) GO TO 2
C****
C**** CHECK CHOPPED CANE CRANE
C****
    1 IF(BUS3.GT.0.0) GO TO 103
C****
C**** IF CRANE NOT BUSY, SET CRANE BUSY AND
C**** PREDICT END OF UNLOADING
C****
  102 ATRIB(1)=TNOW+ERLNG(4,3)
      ATRIB(2)=3.0
      ATRIB(7)=1.0
      CALL FILEM(1)
C**** SET CRANE BUSY AND COLLECT STATS.
      BUS3=1.0
      CALL TIMST(BUS3,TNOW,3)
      TIQ3=0.0
      CALL COLCT(TIQ3,3)
C****
C**** GO TO BRING IN NEXT UNIT FOR WEIGHING
C****
      GO TO 201
C****
C**** AS BUS3=1.0, PUT ARRIVAL IN CHOPPED CANE QUEUE
C****
  103 ATRIB(8)=TNOW
      ATRIB(7)=1.0
      CALL FILEM(3)
      GO TO 201
C****
C**** CHECK WHOLE CANE HOIST
C****
    2 IF(BUS4.GT.0.0) GO TO 105
C****
C**** IF HOIST NOT BUSY, SET HOIST TO BUSY AND
C**** PREDICT END OF UNLOADING
C****
  104 ATRIB(1)=TNOW+ERLNG(5,3)
      ATRIB(2)=3.0
C
      ATRIB(7)=2.0
      CALL FILEM(1)
C****
C**** SET HOIST BUSY AND COLLECT STATS.
      BUS4=1.0
      CALL TIMST(BUS4,TNOW,4)
      TIQ4=0.0
      CALL COLCT(TIQ4,4)
C****
C**** GO TO BRING IN NEXT UNIT FOR WEIGHING
      GO TO 201
C****
C**** AS BUS4=1.0, PUT ARRIVAL IN WHOLE CANE QUEUE
C****
  105 ATRIB(9)=TNOW
      ATRIB(7)=2.0
      CALL FILEM(4)
      GO TO 201
```

```
  201 IF(NNQ(2)) 112,113,114
C****
C**** IF Q2=0, SET SCALE FREE AND COLLECT STATS.
  113 BUS2=0.0
      CALL TIMST(BUS2,TNOW,2)
      RETURN
C****
C**** IF VEHICLE IS IN Q2, REMOVE 1ST ENTRY AND
C**** SCHEDULE END OF WEIGHING
  114 CALL RMOVE(MFE(2),2)
      ATRIB(1)=TNOW+ERLNG(3,2)
      ATRIB(2)=2.0
      CALL FILEM(1)
C**** SET SCALE BUSY AND COLLECT STATS.
      BUS2=1.0
      CALL TIMST(BUS2,TNOW,2)
C**** CALCULATE TIME IN QUEUE
      TIQ2=TNOW-ATRIB(4)
      CALL COLCT(TIQ2,2)
      RETURN
C
  112 CALL ERROR(92)
      STOP
      END
```

```
C****
C****
      SUBROUTINE ENDULD
C****
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/XISYS,TISYS,TIQ2,TIQ3,TIQ4,BUS2,BUS3,BUS4,XVW
C
C**** DETERMINE IF THIS IS WHOLE CANE OR CHOPPED CANE
      KJ=IFIX(ATRIB(5)+0.5)
C**** DETERMINE KIND OF UNIT THIS IS FOR UNLOADING
      KL=IFIX(ATRIB(6)+0.5)
C**** UNIT GOING OUT, REDUCE NUMBER IN SYSTEM BY ONE
      XISYS=XISYS-1.0
C**** COLLECT STATISTICS
C****
      CALL TIMST(XISYS,TNOW,1)
C**** CALCULATE NUMBER OF VEHICLES THROUGH YARD
      XVW=XVW+1.0
C****
C**** CALCULATE TIME IN SYSTEM AND COLLECT STATS.
C****
      TISYS=TNOW-ATRIB(3)
      CALL COLCT(TISYS,1)
C****
C**** CHECK TYPE OF UNIT JUST LEAVING UNLOADER
      IF(KL.EQ.2) GO TO 2
    1 IF(ATRIB(7).GT.1.0) GO TO 53
C**** CHECK STATUS OF QUEUE 3
      IF(NNQ(3))50,51,52
C**** IF Q3=0, SET CRANE FREE AND COLLECT STATS.
   51 BUS3=0.0
      CALL TIMST(BUS3,TNOW,3)
      RETURN
C****
C**** REMOVE 1ST ENTRY IN Q3 AND SCHEDULE END OF UNLOADING
   52 CALL RMOVE(MFE(3),3)
      ATRIB(1)=TNOW+ERLNG(4,3)
      ATRIB(2)=3.0
C
      CALL FILEM(1)
C****
C**** SET CRANE BUSY AND COLLECT STATS.
      BUS3=1.0
      CALL TIMST(BUS3,TNOW,3)
C****
C**** CALCULATE TIME IN QUEUE 3
      TIQ3=TNOW-ATRIB(8)
      CALL COLCT(TIQ3,3)
      RETURN
    2 GO TO 53
C****
C**** CHECK STATUS OF QUEUE 4
   53 IF(NNQ(4))50,54,55
C****
C**** IF Q4=0 SET HOIST FREE AND COLLECT STATS.
   54 BUS4=0.0
      CALL TIMST(BUS4,TNOW,4)
      RETURN
C****
C**** IF Q4.GT.0 REMOVE 1ST ENTRY IN Q4 AND SCHEDULE END-OF-UNLOADING
   55 CALL RMOVE(MFE(4),4)
      ATRIB(1)=TNOW+ERLNG(5,3)
      ATRIB(2)=3.0
C
      CALL FILEM(1)
C****
C**** SET HOIST BUSY AND COLLECT STATS.
      BUS4=1.0
      CALL TIMST(BUS4,TNOW,4)
C****
C**** CALCULATE TIME IN QUEUE 4
      TIQ4=TNOW-ATRIB(9)
      CALL COLCT(TIQ4,4)
      RETURN
```

```
      50 CALL ERROR(93)
         STOP
C
         END
```

```
****
C****
      SUBROUTINE OTPUT
C
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/XISYS,TISYS,TIQ2,TIQ3,TIQ4,BUS2,BUS3,BUS4,XVW
C
      WRITE(NPRNT,100) PPARM(1,1),PPARM(2,1)
      AWGHT = PPARM(3,1)*PPARM(3,4)
      AULDTC = PPARM(4,1)*PPARM(4,4)
      AULDTH = PPARM(5,1)*PPARM(5,4)
      WRITE(NPRNT,101) AULDTC,AULDTH,XVW
      RETURN
C
  100 FORMAT(/15X,"MEAN INTER-ARRIVAL TIME FOR CHOPPED-CANE VEHICLES = "
     1,F5.2/,15X,"MEAN INTER-ARRIVAL TIME FOR WHOLE-CANE VEHICLES   = ",
     2F5.2)
  101 FORMAT(/15X,"MEAN UNLOADING TIME FOR CHOPPED-CANE VEHICLES     = "
     1,F5.2/,15X,"MEAN UNLOADING TIME FOR WHOLE-CANE VEHICLES       = ",
     2F5.2/,15X,"NUMBER OF CANE TRANSPORT UNITS THROUGH YARD       = ",
     3F7.2)
C
      END
```

```
                              SIMULATION PROJECT NUMBER 100  BY    HARVEY

                              DATE  7/  9/ 1982       RUN NUMBER    1 OF    1
                              LLSUP=000000000000000   GASP IV VERSION 23JUN73

NNCLT=     4    NNSTA=     4    NNHIS=     0    NNPRM=     5    NNPLT=     0    NNSTR=     3    NNTRY=   150
NNATR=     9    NNFIL=     4    NNSET=  4000    NNEQD=     0    NNEQS=     0    NFLAG=     0

COLCT NO.  1    LLABC=TISYS
COLCT NO.  2    LLABC=TIQ2
COLCT NO.  3    LLABC=TIQ3
COLCT NO.  4    LLABC=TIQ4

TIMST NO.  1    LLABT=XISYS     I.C. =     0.
TIMST NO.  2    LLABT=BUS2      I.C. =     0.
TIMST NO.  3    LLABT=BUS3      I.C. =     0.
TIMST NO.  4    LLABT=BUS4      I.C. =     0.

KKRNK= (   4)     4      4      4

IINN = (   1)     3      3      3

PARAMETER SET     1 =      .7100E+01     0.             .5460E+02      .1000E+01
PARAMETER SET     2 =      .5200E+01     0.             .5350E+02      .1000E+01
PARAMETER SET     3 =      .3400E+00      .8700E+00     .8500E+01      .1020E+02
PARAMETER SET     4 =      .1500E+01      .2200E+01     .8100E+01      .2500E+01
PARAMETER SET     5 =      .9200E+00      .1800E+01     .4800E+01      .3100E+01

MSTOP=     1    JJCLR=     1    JJBEG=     1    IICRD=     0    TTBEG=     0.          TTFIN=     .7000E+03
JJFIL=     1
IISED= 44391          43183          19249
```

```
**GASP FILE STORAGE AREA DUMP AT TIME  O.          **

MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA =  2

                PRINTOUT OF FILE NUMBER    1
                    TNOW =  O.
                    QQTIM=  O.

                      FILE CONTENTS
ENTRY   1   =   O.            .1000E+01    O.            O.                 .1000E+01    .1000E+01
                 .1000E+01     O.          O.
ENTRY   2   =   .5000E+00     .1000E+01    .5000E+00     O.                 .2000E+01    .2000E+01
                 .2000E+01     O.          O.

                PRINTOUT OF FILE NUMBER    2
                    TNOW =  O.
                    QQTIM=  O.

                    THE FILE IS EMPTY

                PRINTOUT OF FILE NUMBER    3
                    TNOW =  O.
                    QQTIM=  O.

                    THE FILE IS EMPTY

                PRINTOUT OF FILE NUMBER    4
                    TNOW =  O.
                    QQTIM=  O.

                    THE FILE IS EMPTY
```

INTERMEDIATE RESULTS

```
MEAN INTER-ARRIVAL TIME FOR CHOPPED-CANE VEHICLES =  7.10
MEAN INTER-ARRIVAL TIME FOR WHOLE-CANE VEHICLES   =  5.20

MEAN UNLOADING TIME FOR CHOPPED-CANE VEHICLES     =  3.75
MEAN UNLOADING TIME FOR WHOLE-CANE VEHICLES       =  2.85
NUMBER OF CANE TRANSPORT UNITS THROUGH YARD       =  210.00
```

GASP SUMMARY REPORT

SIMULATION PROJECT NUMBER 100 BY HARVEY

DATE 7/ 9/ 1982 RUN NUMBER 1 OF 1

CURRENT TIME = .7000E+03

PARAMETER SET 1 =	.7100E+01	0.	.5460E+02	.1000E+01
PARAMETER SET 2 =	.5200E+01	0.	.5350E+02	.1000E+01
PARAMETER SET 3 =	.3400E+00	.8700E+00	.8500E+01	.1020E+02
PARAMETER SET 4 =	.1500E+01	.2200E+01	.8100E+01	.2500E+01
PARAMETER SET 5 =	.9200E+00	.1800E+01	.4800E+01	.3100E+01

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN	STD DEV	SD OF MEAN	CV	MINIMUM	MAXIMUM	OBS
TISYS	.7398E+02	.2561E+02	.1767E+01	.3462E+00	.6053E+01	.1194E+03	210
TIQ2	.6742E+02	.2549E+02	.1751E+01	.3781E+00	0.	.1138E+03	212
TIQ3	.2957E+00	.7716E+00	.8469E-01	.2610E+01	0.	.4606E+01	83
TIQ4	.2407E+00	.5845E+00	.5166E-01	.2428E+01	0.	.2614E+01	128

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN	STD DEV	MINIMUM	MAXIMUM	TIME INTERVAL	CUR. VALUE
XISYS	.2381E+02	.7015E+01	0.	.3700E+02	.7000E+03	.2900E+02
BUS2	.9966E+00	.5818E-01	0.	.1000E+01	.7000E+03	.1000E+01
BUS3	.4077E+00	.4914E+00	0.	.1000E+01	.7000E+03	0.
BUS4	.5083E+00	.4999E+00	0.	.1000E+01	.7000E+03	.1000E+01

GASP FILE STORAGE AREA DUMP AT TIME .7000E+03

MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA = 39

PRINTOUT OF FILE NUMBER 1

TNOW = .7000E+03

QQTIM= .6991E+03

TIME PERIOD FOR STATISTICS	.7000E+03
AVERAGE NUMBER IN FILE	3.9126
STANDARD DEVIATION	.5423
MAXIMUM NUMBER IN FILE	5

```
                                      FILE CONTENTS
ENTRY  1  =   .7014E+03   .1000E+01   .7014E+03   0.          .1000E+01   .1000E+01
              .1000E+01   0.          0.
ENTRY  2  =   .7028E+03   .3000E+01   .6255E+03   .6255E+03   .2000E+01   .2000E+01
              .2000E+01   0.          0.
ENTRY  3  =   .7029E+03   .2000E+01   .6267E+03   .6267E+03   .2000E+01   .2000E+01
              .2000E+01   0.          0.
ENTRY  4  =   .7031E+03   .1000E+01   .7031E+03   0.          .2000E+01   .2000E+01
              .2000E+01   0.          0.

                                PRINTOUT OF FILE NUMBER   2
                                    TNOW =    .7000E+03
                                    QQTIM=    .6991E+03

                             TIME PERIOD FOR STATISTICS  .7000E+03
                             AVERAGE NUMBER IN FILE        21.8209
                             STANDARD DEVIATION             6.9811
                             MAXIMUM NUMBER IN FILE        35

                                      FILE CONTENTS
ENTRY  1  =   .6279E+03   .1000E+01   .6275E+03   .6275E+03   .2000E+01   .2000E+01
              .2000E+01   0.          0.
ENTRY  2  =   .6374E+03   .1000E+01   .6279E+03   .6279E+03   .2000E+01   .2000E+01
              .2000E+01   0.          0.
ENTRY  3  =   .6439E+03   .1000E+01   .6374E+03   .6374E+03   .2000E+01   .2000E+01
              .2000E+01   0.          0.
ENTRY  4  =   .6467E+03   .1000E+01   .6397E+03   .6397E+03   .1000E+01   .1000E+01
              .1000E+01   0.          0.
ENTRY  5  =   .6478E+03   .1000E+01   .6439E+03   .6439E+03   .2000E+01   .2000E+01
              .2000E+01   0.          0.
ENTRY  6  =   .6469E+03   .1000E+01   .6467E+03   .6467E+03   .1000E+01   .1000E+01
              .1000E+01   0.          0.
ENTRY  7  =   .6491E+03   .1000E+01   .6469E+03   .6469E+03   .1000E+01   .1000E+01
              .1000E+01   0.          0.
ENTRY  8  =   .6499E+03   .1000E+01   .6478E+03   .6478E+03   .2000E+01   .2000E+01
              .2000E+01   0.          0.
ENTRY  9  =   .6593E+03   .1000E+01   .6491E+03   .6491E+03   .1000E+01   .1000E+01
              .1000E+01   0.          0.
ENTRY 10  =   .6599E+03   .1000E+01   .6499E+03   .6499E+03   .2000E+01   .2000E+01
              .2000E+01   0.          0.
ENTRY 11  =   .6600E+03   .1000E+01   .6593E+03   .6593E+03   .1000E+01   .1000E+01
              .1000E+01   0.          0.
ENTRY 12  =   .6670E+03   .1000E+01   .6599E+03   .6599E+03   .2000E+01   .2000E+01
              .2000E+01   0.          0.
ENTRY 13  =   .6658E+03   .1000E+01   .6600E+03   .6600E+03   .1000E+01   .1000E+01
```

```
                          .1000E+01      O.             O.
ENTRY   14      =         .6717E+03      .1000E+01      .6658E+03      .6658E+03      .1000E+01      .1000E+01
                          .1000E+01      O.             O.
ENTRY   15      =         .6757E+03      .1000E+01      .6670E+03      .6670E+03      .2000E+01      .2000E+01
                          .2000E+01      O.             O.
ENTRY   16      =         .6753E+03      .1000E+01      .6717E+03      .6717E+03      .1000E+01      .1000E+01
                          .1000E+01      O.             O.
ENTRY   17      =         .6790E+03      .1000E+01      .6753E+03      .6753E+03      .1000E+01      .1000E+01
                          .1000E+01      O.             O.
ENTRY   18      =         .6774E+03      .1000E+01      .6757E+03      .6757E+03      .2000E+01      .2000E+01
                          .2000E+01      O.             O.
ENTRY   19      =         .6785E+03      .1000E+01      .6774E+03      .6774E+03      .2000E+01      .2000E+01
                          .2000E+01      O.             O.
ENTRY   20      =         .6812E+03      .1000E+01      .6785E+03      .6785E+03      .2000E+01      .2000E+01
                          .2000E+01      O.             O.
ENTRY   21      =         .6901E+03      .1000E+01      .6790E+03      .6790E+03      .1000E+01      .1000E+01
                          .1000E+01      O.             O.
ENTRY   22      =         .6841E+03      .1000E+01      .6812E+03      .6812E+03      .2000E+01      .2000E+01
                          .2000E+01      O.             O.
ENTRY   23      =         .6878E+03      .1000E+01      .6841E+03      .6841E+03      .2000E+01      .2000E+01
                          .2000E+01      O,             O.
ENTRY   24      =         .6899E+03      .1000E+01      .6878E+03      .6878E+03      .2000E+01      .2000E+01
                          .2000E+01      O.             O.
ENTRY   25      =         .7031E+03      .1000E+01      .6899E+03      .6899E+03      .2000E+01      .2000E+01
                          .2000E+01      O.             O.
ENTRY   26      =         .6960E+03      .1000E+01      .6901E+03      .6901E+03      .1000E+01      .1000E+01
                          .1000E+01      O.             O.
ENTRY   27      =         .7014E+03      .1000E+01      .6960E+03      .6960E+03      .1000E+01      .1000E+01
                          .1000E+01      O.             O.

                    PRINTOUT OF FILE NUMBER   3
                        1NOW =    .7000E+03
                        QOTIM=    .6071E+03

                TIME PERIOD FOR STATISTICS  .7000E+03
                AVERAGE NUMBER IN FILE          .0351
                STANDARD DEVIATION              .1870
                MAXIMUM NUMBER IN FILE         2

                        THE FILE IS EMPTY
```

```
PRINTOUT OF FILE NUMBER   4
    TNOW =    .7000E+03
    QQTIM=    .6781E+03

TIME PERIOD FOR STATISTICS  .7000E+03
AVERAGE NUMBER IN FILE          .0440
STANDARD DEVIATION              .2051
MAXIMUM NUMBER IN FILE         1

    THE FILE IS EMPTY
```

```
.11.01.18. 09/21/82     SHEETS PRINT                18  $     .56
.11.01.18. 09/21/82     LINES PRINT                622
.11.01.18. 09/21/82     LINES READ                 609
.11.01.18. 09/21/82     TOTAL LINES PROCESSED      615  $     .49
.11.01.18. 09/21/82     COST AT RG2                     $    1.05
```

Results for

Extended work period

Simulation time = 960 minutes

****INTERMEDIATE RESULTS****

MEAN INTER-ARRIVAL TIME FOR CHOPPED-CANE VEHICLES	=	7.10
MEAN INTER-ARRIVAL TIME FOR WHOLE-CANE VEHICLES	=	5.20
MEAN UNLOADING TIME FOR CHOPPED-CANE VEHICLES	=	3.75
MEAN UNLOADING TIME FOR WHOLE-CANE VEHICLES	=	2.85
NUMBER OF CANE TRANSPORT UNITS THROUGH YARD	=	289.00

GASP SUMMARY REPORT

SIMULATION PROJECT NUMBER 100 BY HARVEY

DATE 7/ 9/ 1982 RUN NUMBER 1 OF 1

CURRENT TIME = .9600E+03

PARAMETER SET	1 =	.7100E+01	0.	.5460E+02	.1000E+01
PARAMETER SET	2 =	.5200E+01	0.	.5350E+02	.1000E+01
PARAMETER SET	3 =	.3400E+00	.8700E+00	.8500E+01	.1020E+02
PARAMETER SET	4 =	.1500E+01	.2200E+01	.8100E+01	.2500E+01
PARAMETER SET	5 =	.9200E+00	.1800E+01	.4800E+01	.3100E+01

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN	STD DEV	SD OF MEAN	CV	MINIMUM	MAXIMUM	OBS
TISYS	.8283E+02	.2820E+02	.1659E+01	.3404E+00	.6053E+01	.1437E+03	289
TIQ2	.7663E+02	.2855E+02	.1674E+01	.3726E+00	0.	.1382E+03	291
TIQ3	.2709E+00	.7412E+00	.7004E-01	.2736E+01	0.	.4606E+01	112
TIQ4	.2775E+00	.5959E+00	.4466E-01	.2148E+01	0.	.2614E+01	178

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN	STD DEV	MINIMUM	MAXIMUM	TIME INTERVAL	CUR. VALUE
XISYS	.2753E+02	.8839E+01	0.	.4500E+02	.9600E+03	.3900E+02
BUS2	.9975E+00	.4971E-01	0.	.1000E+01	.9600E+03	.1000E+01
BUS3	.3937E+00	.4886E+00	0.	.1000E+01	.9600E+03	.1000E+01
BUS4	.5265E+00	.4993E+00	0.	.1000E+01	.9600E+03	0.

Modified subroutines

ARIVAL and ENDWGH

for 1-queue, 2-scale configuration

```
C****
C****
C**** SUBROUTINE TO HANDLE ARRIVAL OF 2-WAGON TRAINS AT FACTORY
C
      SUBROUTINE ARIVAL
C****
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/XISYS,TISYS,TIQ2,TIQ3,TIQ4,BUS2,BUS3,BUS4,BUS5,XVW
C
C**** DETERMINE TYPE OF VEHICLE FOR WEIGHING
      KJ=IFIX(ATRIB(5)+0.5)
C**** DETERMINE IF THIS IS WHOLE CANE OR CHOPPED CANE
      KL=IFIX(ATRIB(6)+0.5)
C**** SET TIME OF NEXT ARRIVAL
C
      ATRIB(1)=TNOW+ERLNG(KJ,1)
      ATRIB(2)=1.0
      ATRIB(3)=ATRIB(1)
      CALL FILEM(1)
C****
C**** ADD ONE TO NUMBER IN SYSTEM AND COLLECT STATS.
C****
      XISYS=XISYS+1.0
      CALL TIMST(XISYS,TNOW,1)
      ATRIB(3)=TNOW
C****
C**** CHECK SCALE 2
C**** IF SCALE NOT BUSY, GO TO SCALE AND PREDICT END OF WEIGHING
C****
      IF(BUS2) 111,104,105
  104 BUS2=1.0
      CALL TIMST(BUS2,TNOW,2)
      ATRIB(1)=TNOW+ERLNG(3,2)
      ATRIB(2)=2.0
      CALL FILEM(1)
C**** SET TIME IN Q2 AND COLLECT STATS.
      TIQ2=0.0
      CALL COLCT(TIQ2,2)
      RETURN
C****
C**** IF SCALE 2 BUSY, CHECK SCALE 1
C****
  105 IF(BUS5) 111,106,107
C**** IF SCALE 1 FREE, SET BUSY AND PREDICT END OF WEIGHING
  106 BUS5=1.0
      CALL TIMST(BUS5,TNOW,5)
      ATRIB(1)=TNOW+ERLNG(6,2)
      ATRIB(2)=2.0
      CALL FILEM(1)
      TIQ2=0.0
      CALL COLCT(TIQ2,2)
      RETURN
C****
C**** IF SCALE 1 IS BUSY, PUT ARRIVAL IN Q2 AND RECORD TIME IN.
C
  107 ATRIB(4)=TNOW
      CALL FILEM(2)
      RETURN
C
  111 CALL ERROR(87)
      STOP
      END
```

```
C****
C****
C**** SUBROUTINE TO HANDLE VEHICLES AT END OF WEIGHING
C****
      SUBROUTINE ENDWGH
C****
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/XISYS,TISYS,TIQ2,TIQ3,TIQ4,BUS2,BUS3,BUS4,BUS5,XVW
C****
C**** DETERMINE TYPE OF VEHICLE FOR WEIGHING
      KJ=IFIX(ATRIB(5)+0.5)
C**** DETERMINE IF THIS IS WHOLE CANE OR CHOPPED CANE
      KL=IFIX(ATRIB(6)+0.5)
C****
C**** SEND WEIGHED VEHICLE TO CHOPPED CANE CRANE OR WHOLE CANE HOIST
C****
      IF(KL.EQ.2) GO TO 2
C****
C**** CHECK CHOPPED CANE CRANE
C****
    1 IF(BUS3.GT.0.0) GO TO 103
C****
C**** IF CRANE NOT BUSY, SET CRANE BUSY AND
C**** PREDICT END OF UNLOADING
C****
  102 ATRIB(1)=TNOW+ERLNG(4,3)
      ATRIB(2)=3.0
      ATRIB(7)=1.0
      CALL FILEM(1)
C**** SET CRANE BUSY AND COLLECT STATS.
      BUS3=1.0
      CALL TIMST(BUS3,TNOW,3)
      TIQ3=0.0
      CALL COLCT(TIQ3,3)
C****
C**** GO TO BRING IN NEXT UNIT FOR WEIGHING
C****
      GO TO 201
C****
C**** AS BUS3=1.0, PUT ARRIVAL IN CHOPPED CANE QUEUE
C****
  103 ATRIB(8)=TNOW
      ATRIB(7)=1.0
      CALL FILEM(3)
      GO TO 201
C****
C**** CHECK WHOLE CANE HOIST
C****
    2 IF(BUS4.GT.0.0) GO TO 105
C****
C**** IF HOIST NOT BUSY, SET HOIST TO BUSY AND
C**** PREDICT END OF UNLOADING
C****
  104 ATRIB(1)=TNOW+ERLNG(5,3)
      ATRIB(2)=3.0
C
      ATRIB(7)=2.0
      CALL FILEM(1)
C****
C**** SET HOIST BUSY AND COLLECT STATS.
      BUS4=1.0
      CALL TIMST(BUS4,TNOW,4)
      TIQ4=0.0
      CALL COLCT(TIQ4,4)
C****
C**** GO TO BRING IN NEXT UNIT FOR WEIGHING
      GO TO 201
C****
C**** AS BUS4=1.0, PUT ARRIVAL IN WHOLE CANE QUEUE
C****
  105 ATRIB(9)=TNOW
      ATRIB(7)=2.0
      CALL FILEM(4)
      GO TO 201
C****
```

SUBROUTINE ENDWGH


```
  201 IF(NNQ(2)) 112,113,114
C****
C**** IF Q2=0, SET SCALE FREE AND COLLECT STATS.
  113 BUS2=0.0
      CALL TIMST(BUS2,TNOW,2)
      RETURN
C****
C**** IF VEHICLE IS IN Q2, CHECK SCALES
C**** IF VEHICLE IS IN Q2, REMOVE 1ST ENTRY AND
C**** SCHEDULE END OF WEIGHING
C****
  114 CALL RMOVE(MFE(2),2)
      ATRIB(1)=TNOW+ERLNG(3,2)
      ATRIB(2)=2.0
      CALL FILEM(1)
C**** SET SCALE BUSY AND COLLECT STATS.
      BUS2=1.0
      CALL TIMST(BUS2,TNOW,2)
C**** CALCULATE TIME IN QUEUE
      TIQ2=TNOW-ATRIB(4)
      CALL COLCT(TIQ2,2)
C
C**** IF SCALE 2 BUSY, CHECK SCALE 1
      IF(NNQ(2)) 112,116,117
  116 BUS5=0.0
      CALL TIMST(BUS5,TNOW,5)
      RETURN
  117 CALL RMOVE(MFE(2),2)
      ATRIB(1)=TNOW+ERLNG(6,2)
      ATRIB(2)=2.0
      CALL FILEM(1)
      BUS5=1.0
      CALL TIMST(BUS5,TNOW,5)
      TIQ2=TNOW-ATRIB(4)
      CALL COLCT(TIQ2,2)
      RETURN
C
C
  112 CALL ERROR(92)
      STOP
      END
```

Modified Subroutines

ARIVAL and ENDWGH

for 2-queue, 2-scale configuration

```
C****
C****
C**** SUBROUTINE TO HANDLE ARRIVAL OF 2-WAGON TRAINS AT FACTORY
C
      SUBROUTINE ARIVAL
C****
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/XISYS,TISYS,TIQ2,TIQ3,TIQ4,TIQ5,BUS2,BUS3,BUS4,BUS5,
     1XVW
C
C**** DETERMINE TYPE OF VEHICLE FOR WEIGHING
      KJ=IFIX(ATRIB(5)+0.5)
C**** DETERMINE IF THIS IS WHOLE CANE OR CHOPPED CANE
      KL=IFIX(ATRIB(6)+0.5)
C**** SET TIME OF NEXT ARRIVAL
C
      ATRIB(1)=TNOW+ERLNG(KJ,1)
      ATRIB(2)=1.0
      ATRIB(3)=ATRIB(1)
      CALL FILEM(1)
C****
C**** ADD ONE TO NUMBER IN SYSTEM AND COLLECT STATS.
C****
      XISYS=XISYS+1.0
      CALL TIMST(XISYS,TNOW,1)
      ATRIB(3)=TNOW
C****
C**** SEND TRANSPORT UNIT TO CORRECT SCALE
C
      IF(KJ.EQ.2) GO TO 106
C**** IF A CHOPPED CANE UNIT, GO TO SCALE #1
C**** IF SCALE NOT BUSY, GO TO SCALE AND PREDICT END OF WEIGHING
C****
      IF(BUS2) 111,104,105
  104 BUS2=1.0
      CALL TIMST(BUS2,TNOW,2)
      ATRIB(1)=TNOW+ERLNG(3,2)
      ATRIB(2)=2.0
      CALL FILEM(1)
C**** SET TIME IN Q2 AND COLLECT STATS.
      TIQ2=0.0
      CALL COLCT(TIQ2,2)
      RETURN
C****
C**** IF SCALE IS BUSY, PUT ARRIVAL IN Q2 AND RECORD TIME IN;
C****
  105 ATRIB(4)=TNOW
      CALL FILEM(2)
      RETURN
C****
C**** IF WHOLE CANE UNIT, GO TO SCALE #2
C
  106 IF(BUS5) 111,107,108
  107 BUS5=1.0
      CALL TIMST(BUS5,TNOW,5)
      ATRIB(1)=TNOW+ERLNG(6,2)
      ATRIB(2)=2.0
      CALL FILEM(1)
C**** SET TIME IN Q5 AND COLLECT STATS.
      TIQ5=0.0
      CALL COLCT(TIQ5,5)
      RETURN
C****
C**** IF SCALE 2 IS BUSY, PUT ARRIVAL IN Q5, RECORD TIME IN.
C
  108 ATRIB(4)=TNOW
      CALL FILEM(5)
      RETURN
C
  111 CALL ERROR(87)
      STOP
      END
```

```
C****
C****
C**** SUBROUTINE TO HANDLE VEHICLES AT END OF WEIGHING
C****
      SUBROUTINE ENDWGH
C****
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCOM1/XISYS,TISYS,TIQ2,TIQ3,TIQ4,TIQ5,BUS2,BUS3,BUS4,BUS5,
     1XVW
C****
C**** DETERMINE TYPE OF VEHICLE FOR WEIGHING
      KJ=IFIX(ATRIB(5)+0.5)
C**** DETERMINE IF THIS IS WHOLE CANE OR CHOPPED CANE
      KL=IFIX(ATRIB(6)+0.5)
C****
C**** SEND WEIGHED VEHICLE TO CHOPPED CANE CRANE OR WHOLE CANE HOIST
C****
      IF(KL.EQ.2) GO TO 2
C****
C**** CHECK CHOPPED CANE CRANE
C****
    1 IF(BUS3.GT.0.0) GO TO 103
C****
C**** IF CRANE NOT BUSY, SET CRANE BUSY AND
C**** PREDICT END OF UNLOADING
C****
  102 ATRIB(1)=TNOW+ERLNG(4,3)
      ATRIB(2)=3.0
      ATRIB(7)=1.0
      CALL FILEM(1)
C**** SET CRANE BUSY AND COLLECT STATS.
      BUS3=1.0
      CALL TIMST(BUS3,TNOW,3)
      TIQ3=0.0
      CALL COLCT(TIQ3,3)
C****
C**** GO TO BRING IN NEXT CHOPPED CANE UNIT FOR WEIGHING
C****
      GO TO 201
C****
C**** AS BUS3=1.0, PUT ARRIVAL IN CHOPPED CANE QUEUE
C****
  103 ATRIB(8)=TNOW
      ATRIB(7)=1.0
      CALL FILEM(3)
      GO TO 201
C****
C**** CHECK WHOLE CANE HOIST
C****
    2 IF(BUS4.GT.0.0) GO TO 105
C****
C**** IF HOIST NOT BUSY, SET HOIST TO BUSY AND
C**** PREDICT END OF UNLOADING
C****
  104 ATRIB(1)=TNOW+ERLNG(5,3)
      ATRIB(2)=3.0
C
      ATRIB(7)=2.0
      CALL FILEM(1)
C****
C**** SET HOIST BUSY AND COLLECT STATS.
      BUS4=1.0
      CALL TIMST(BUS4,TNOW,4)
      TIQ4=0.0
      CALL COLCT(TIQ4,4)
C****
C**** GO TO BRING IN NEXT WHOLE CANE UNIT FOR WEIGHING
      GO TO 202
C****
C**** AS BUS4=1.0, PUT ARRIVAL IN WHOLE CANE QUEUE
C****
  105 ATRIB(9)=TNOW
      ATRIB(7)=2.0
      CALL FILEM(4)
      GO TO 202
```

```
C****
  201 IF(NNQ(2)) 112,113,114
C****
C**** IF Q2=0, SET SCALE FREE AND COLLECT STATS.
  113 BUS2=0.0
      CALL TIMST(BUS2,TNOW,2)
      RETURN
C****
C**** IF VEHICLE IS IN Q2, REMOVE 1ST ENTRY AND
C**** SCHEDULE END OF WEIGHING
C****
  114 CALL RMOVE(MFE(2),2)
      ATRIB(1)=TNOW+ERLNG(3,2)
      ATRIB(2)=2.0
      CALL FILEM(1)
C**** SET SCALE BUSY AND COLLECT STATS.
      BUS2=1.0
      CALL TIMST(BUS2,TNOW,2)
C**** CALCULATE TIME IN QUEUE
      TIQ2=TNOW-ATRIB(4)
      CALL COLCT(TIQ2,2)
      RETURN
C****
C
  202 IF(NNQ(5)) 112,116,117
C**** IF Q5 IS EMPTY, SET SCALE 2 FREE AND COLLECT STATS.
  116 BUS5=0.0
      CALL TIMST(BUS5,TNOW,5)
      RETURN
C
C**** IF WHOLE CANE UNITS ARE IN Q5, SEND ONE TO SCALE #2
  117 CALL RMOVE(MFE(5),5)
      ATRIB(1)=TNOW+ERLNG(6,2)
      ATRIB(2)=2.0
      CALL FILEM(1)
      BUS5=1.0
      CALL TIMST(BUS5,TNOW,5)
      TIQ5=TNOW-ATRIB(4)
      CALL COLCT(TIQ5,5)
      RETURN
C
C
  112 CALL ERROR(92)
      STOP
      END
```

Results for

Configuration with 1 queue and 2 scales

```
                    **INTERMEDIATE RESULTS**

MEAN INTER-ARRIVAL TIME FOR CHOPPED-CANE VEHICLES =  7.10
MEAN INTER-ARRIVAL TIME FOR WHOLE-CANE VEHICLES   =  5.20

MEAN UNLOADING TIME FOR CHOPPED-CANE VEHICLES     =  3.75
MEAN UNLOADING TIME FOR WHOLE-CANE VEHICLES       =  2.85
NUMBER OF CANE TRANSPORT UNITS THROUGH YARD       =  236.00
```

GASP SUMMARY REPORT

SIMULATION PROJECT NUMBER 100 BY HARVEY

DATE 7/ 9/ 1982 RUN NUMBER 1 OF 1

CURRENT TIME = .7000E+03

PARAMETER SET	1 =	.7100E+01	0.	.5460E+02	.1000E+01
PARAMETER SET	2 =	.5200E+01	0.	.5350E+02	.1000E+01
PARAMETER SET	3 =	.3400E+00	.8700E+00	.8500E+01	.1020E+02
PARAMETER SET	4 =	.1500E+01	.2200E+01	.8100E+01	.2500E+01
PARAMETER SET	5 =	.9200E+00	.1800E+01	.4800E+01	.3100E+01
PARAMETER SET	6 =	.3400E+00	.8700E+00	.8500E+01	.1020E+02

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN	STD DEV ,	SD OF MEAN	CV	MINIMUM	MAXIMUM	OBS
TISYS	.9002E+01	.3538E+01	.2303E+00	.3931E+00	.3852E+01	.2132E+02	236
TIQ2	.9306E+00	.1573E+01	.1017E+00	.1690E+01	0.	.9145E+01	239
TIQ3	.1631E+01	.2887E+01	.2962E+00	.1770E+01	0.	.1106E+02	95
TIQ4	.1754E+01	.2388E+01	.1997E+00	.1361E+01	0.	.1099E+02	143

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN	STD DEV	MINIMUM	MAXIMUM	TIME INTERVAL	CUR. VALUE
XISYS	.3072E+01	.1960E+01	0.	.9000E+01	.7000E+03	.3000E+01
BUS2	.5489E+00	.4976E+00	0.	.1000E+01	.7000E+03	0.
BUS3	.4701E+00	.4991E+00	0.	.1000E+01	.7000E+03	.1000E+01
BUS4	.5720E+00	.4948E+00	0.	.1000E+01	.7000E+03	.1000E+01
BUS5	.6487E+00	.4774E+00	0.	.1000E+01	.7000E+03	.1000E+01

APPENDIX IV

FORTRAN LISTING OF

FIELD OPERATIONS PROGRAM

"FIELDOP"

```
  11/01/82  MSU HUSTLER 2       LSD 51.52  10/30/82  CYBER750
.15.01.59.IB84610
.15.02.00.JOB READ-  11/01/82 .15.00.02.
.15.02.00.HARVEY,RG2,JC1000,L100.
.15.02.01.LAST ACCESS- B 17.12 10/29/82
.15.02.01.RUNS- 0101    PN DOLLAR BALANCE $00067.30
.15.02.01.001026     CARDS READ  VALUE  $0000000.82
.15.02.01.CP-PP SEC.       .000-       .000  $     .00
.15.02.01.DISPOSE,*OUTPUT,PRINTER=PAGE,FORMAT=ELIT
.15.02.01.E,1SIDED.
.15.02.02.RP   00000006  000000000247  MAXFL 025100
.15.02.02.CP-PP SEC.       .011-       .337  $     .01
.15.02.02.FTN.
.15.03.26.       1.313 CP SECONDS COMPILATION TIME
.15.03.26.RP   00000376  000000016343  MAXFL 052000
.15.03.26.CP-PP SEC.      1.328-    44.740  $    1.18
.15.03.26.HAL,GASPIV.
.15.03.27.ZZZZMPL - CYCLE 01, HAL 5, MPL
.15.03.27.FILE ATTACHED
.15.03.27.HAL 5.149
.15.03.28.GASPIV  - CYCLE 01, HAL-GASPIV
.15.03.28.FILE ATTACHED
.15.03.28.RP   00000416  000000016731  MAXFL 025400
.15.03.28.CP-PP SEC.      1.342-    45.728  $    1.22
.15.03.28.LIBRARY,GASPIV.
.15.03.28.CP-PP SEC.      1.343-    45.769  $    1.22
.15.03.28.LDSET,PRESET=ZERO.
.15.03.28.LGO.
.15.04.01.EXEC BEGUN.15.04.01.
.15.04.02.     STOP
.15.04.02.     067100    FINAL EXECUTION FL.
.15.04.02.      0.134 CP SECONDS EXECUTION TIME.
.15.04.02.MAX FILES 0006 MAX PRUS 000100B.
.15.04.02.RP   00000615  000000017624  MAXFL 067100
.15.04.02. PP     49.803 SEC.
.15.04.02.CP USE     1.838 SEC    VALUE$      .36
.15.04.02.PP USE    47.784 SEC    VALUE$      .12
.15.04.02.CM USE     5.235 W-H    VALUE$     1.24
.15.04.02.TOTAL COMPUTE VALUE AT RG2 $     1.72
```

```
      PROGRAM FIELDOP(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C=======================================================================
C     THIS PROGRAM SIMULATES THE FIELD ACTIVITIES INVOLVED IN
C     THE MECHANICAL HARVESTING OF SUGAR CANE, AND ALSO
C     THE ACTIVITIES INVOLVED IN A CYCLIC TRANSPORT SYSTEM OF
C     THE CANE BY WAGONS PULLED BY ROAD TRACTORS FROM FIELD
C     TO THE FACTORY, AND BACK TO THE FIELD.
C=======================================================================
C
C**** LIST OF USER-GENERATED INPUT VARIABLES
C
C               ISC   = 1 :SIMULATE WAGONS
C                     = 0 :END OF SIMULATION
C               NHT       :NUMBER OF HARVESTERS
C               NFT       :NUMBER OF FIELD TRACTORS
C               NRT       :NUMBER OF ROAD TRACTORS
C               NEST      :IDENTIFIES LOCATION SIMULATED
C               QUOTA     :ESTATE DELIVERY QUOTA OF CANE FOR ONE DAY
C               CAP       :AMOUNT OF CANE DELIVERED BY A TRANSPORT
C                          UNIT PER TRIP (TONNES)
C               STM       :START TIME ON THE FIRST DAY
C               ENT       :END TIME ON THE FIRST DAY
C               BREAK     :LUNCH PERIOD BETWEEN END OF FIRST AND
C                          START OF SECOND SHIFT
C               WKTM      :TIME AVAILABLE FOR WORK EACH DAY
C              NRPRT.LE.1:COMPILE DATA FOR SHORT PEPORT
C                   .GT.1:COMPILE DATA FOR LONG REPORT
C              LRPRT.LT.O:PRINT COMPLETE GASPIV REPORT
C                   .GT.O:PRINT FILE CONTENTS AND INPUT DATA ONLY
C
C
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/ ISC,QUOTA,AMOUNT,ENTM,BREAK,STTM,NRT,NHT,NFT,NWG,
     1CAP,BUSHT(2),BUSFT(4),BUSRT(6),TIQE,TIQF,RTRIP,SHFND,WKTM
      COMMON /UCOM2/ DWN,SKLOM
      COMMON /UCOM4/LRPRT,N77,NSHF,NDAY,NEST,NRPRT,KL
      COMMON /UCOM6/ ENT,STM
      EQUIVALENCE (NSET(1),QSET(1))
C****
C
  100 READ(5,1) ISC
      IF(ISC.EQ.0) GO TO 200
      READ(5,2) NWG,NHT,NFT,NRT,NEST,NRPRT,LRPRT
      READ(5,3) QUOTA,CAP
      READ(5,4) STM,ENT,BREAK,WKTM
      NCRDR=5
      NPRNT=6
C
C**** THIS SEGMENT OF CODE PRINTS OUT THE INPUT DATA
C
      IF(ISC.EQ.1) WRITE(6,40) ISC,NWG,NHT,NFT,NRT,NEST
      WRITE(6,50) QUOTA,CAP,STM,ENT,BREAK,WKTM
      WRITE(6,60) NRPRT,LRPRT
      CALL GASP
      GO TO 100
C
    1 FORMAT(2I2)
    2 FORMAT(7I2)
    3 FORMAT(2F10.4)
    4 FORMAT(4E10.4)
   40 FORMAT("1",///,T26,"NON-GASPIV DATA INPUT:",///,T40,"ISC =",
     1I2,/,T40,"NWG =",I2,/,T40,"NHT =",I2,/,T40,"NFT =",I2,
     2/,T40,"NRT =",I2,/,T39,"NEST =",I2)
   50 FORMAT(T38,"QUOTA =",F10.2," TONNES",/,T40,"CAP =",F10.2,
     1" TONNES",//,T40,"STM =",F10.2," MINS",T40,"ENT =",F10.2,
     2" MINS",/,T38,"BREAK =",F10.2," MINS",/,T39,"WKTM =",F10.2,
     3" MINS")
   60 FORMAT(T39,"NRPRT =",I2,/,T39,"LRPRT =",I2)
  200 STOP
      END
```

```
C****
C
      SUBROUTINE INTLC
C=================================================================
C     THIS SUBROUTINE INITIALIZES THE EQUIPMENT COMBINATION TO BE
C     SIMULATED AND RESETS MARKERS AND DATA STORAGE ARRAYS
C=================================================================
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/ ISC,QUOTA,AMOUNT,ENTM,BREAK,STTM,NRT,NHT,NFT,NWG,
     1CAP,BUSHT(2),BUSFT(4),BUSRT(6),TIQE,TIQF,RTRIP,SHFND,WKTM
      COMMON /UCOM2/ DWN,SMILE
      COMMON /UCOM4/ LRPRT,N77,NSHF,NDAY,NEST,NRPRT,KL
      COMMON /UCOM5/ TAB(21,20),KARRAY(21,20),SUM(21),NSUM(21)
      COMMON /UCOM6/ ENT,STM
C****
C     INITIALIZE START,END AND OPERATING TIMES FOR DAY 1
C
      ENTM=ENT
      STTM=STM
      SHFND=STTM+WKTM
C
C**** INITIALIZE DAILY QUOTA ASSIGNED TO THIS EQUIPMENT, RESET MARKERS
C
      AMOUNT=QUOTA
      KL=0
      NDAY=1
      NSHF=0
      N77=0
      DWN=0
C
C****
C**** INITIALIZE DATA STORAGE ARRAYS USED FOR SHORT REPORT
C
      DO 10 I=1,21
         SUM(I)=0.0
         NSUM(I)=0.0
      DO 10 J=1,20
         KARRAY(I,J)=0
   10 TAB(I,J)=0.0
C
C**** INITIALIZE WAGONS, FIELD TRACTORS, HARVESIERS AND ROAD TRACTORS
C
  200 DO 210 I=1,NRT
         BUSRT(I)=0.0
         CALL TIMST(BUSRT(I),TNOW,(I+4))
         ATRIB(3)=0.0
         ATRIB(10)=I
         ATRIB(11)=2.0
         ATRIB(13)=NEST
         CALL FILEM(4)
  210 CONTINUE
C
C**** INITIALIZE WAGONS
      DO 220 K=1,NWG
         ATRIB(3)=STTM
         ATRIB(13)=NEST
         CALL FILEM(2)
  220 CONTINUE
C
C**** SET UP LOADING OPERATION AND PREDICT END-OF LOADING
C**** FOR EACH HARVESTER
C
       INHT=NHT
      DO 230 I=1,NFT
         CALL RMOVE(MFE(2),2)
         TIQE=0.0
         CALL COLCT(TIQE,2)
         ATRIB(9)=I
         BUSFT(I)=1.0
         CALL TIMST(BUSFT(I),TNOW,(I+2))
         IF(INHT.GT.0) GO TO 225
         ATRIB(1)=TNOW+2.0
         ATRIB(2)=4.0
         CALL FILEM(1)
         GO TO 230
```

```
  225     INHT=INHT-1
          ATRIB(8)=1
          BUSHT(1)=1.0
          CALL TIMST(BUSHT(1),TNOW,1)
          ATRIB(1)=TNOW+GAMA(1,1)+PPARM(8,1)
          ATRIB(2)=3.0
          CALL FILEM(1)
  230 CONTINUE
C
C**** SET SHUTDOWN TIME FOR THIS SHIFT
C
  300 ATRIB(1)=SHFND
      ATRIB(2)=7.0
      CALL FILEM(1)
  400 RETURN
      END
```

```
C****
      SUBROUTINE EVNTS(IX)
C=====================================================================
C     THIS SUBROUTINE IDENTIFIES THE EVENTS TO BE PROCESSED BASED
C     ON THE VALUE OF ATRIB(2)
C=====================================================================
      GO TO (100,200,300,400,500,600,700,800),IX
  100 CALL ARFLD
      RETURN
  200 CALL STLD
      RETURN
  300 CALL NDLD
      RETURN
  400 CALL ARHTR
      RETURN
  500 CALL ARFCT
      RETURN
  600 CALL DPFCT
      RETURN
  700 CALL SHTDN
      RETURN
  800 CALL STRTUP
      RETURN
      END
```

```
C****
      SUBROUTINE ARFLD
C=====================================================================
C     THIS SUBROUTINE SIMULATES THE ACTIVITIES AT THE FIELD WHEN
C     A TRANSPORT UNIT RETURNS
C=====================================================================
C
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/ ISC,QUOTA,AMOUNT,ENTM,BREAK,STTM,NRT,NHT,NFT,NWG,
     1CAP,BUSHT(2),BUSFT(4),BUSRT(6),TIOE,TIOF,RTRIP,SHFND,WKTM
      COMMON /GCOM5/ IIEVT,IISED(6),JJBEG,JJCLR,MMNIT,MMON,NNAME(3),NNOF
     1I,NNDAY,NNPT,NNSET,NNPRJ,NNPRM,NNRNS,NNRUN,NNSTR,NNYR,SSEED(6)
      COMMON /UCOM2/ DWN,SMILE
C
C**** CHECK STATUS OF ARRIVING VEHICLE) IF ATRIB(12).GT.0 REDUCE
C**** QUOTA BY CAP. IF ATRIB(12).EQ.0, VEHICLE IS RETURNING FROM
C**** LOCATION OTHER THAN FACTORY - FOR EXAMPLE THE WORKSHOP.
      IF(ATRIB(12)) 300,200,100
C
C**** CALCULATE AMOUNT OF DAY"S QUOTA REMAINING AND
C**** COMPUTE ROUND-TRIP TIME
C
  100 AMOUNT=AMOUNT-CAP
      RTRIP=TNOW-ATRIB(5)
      CALL COLCT(RTRIP,1)
      ATRIB(12)=0.0
C
C**** PARK EMPTY WAGONS IN QUEUE 2
C****
  200 N11=INT(ATRIB(11))
      DO 201 I=1,N11
          ATRIB(3)=TNOW
          CALL FILEM(2)
  201 CONTINUE
C
C**** PARK ROAD TRACTOR IN QUEUE 4
      CALL FILEM(4)
C
C**** CHECK STATUS OF SYSTEM
      IF(DWN.EQ.1.0) RETURN
C
C**** CHECK WHETHER QUOTA IS FULFILLED. IF YES, SCHEDULE SHUTDOWN
C
      IF(AMOUNT.LE.0.0) GO TO 250
C
C**** CHECK NUMBER OF HARVESTERS IDLE
    5 N1=NNQ(1)
      DO 2 I=1,N1
          HTOC=NFIND(2.0,5,1,2,1.0)
          IF(HTOC.GT.0) GO TO 1
          IF(NNQ(9).GT.0) GO TO 7
          N9=0
          GO TO 4
    1     CALL RMOVE(HTOC,1)
          CALL FILEM(9)
    2 CONTINUE
    7 N9=NNQ(9)
      N99=N9
      DO 3 I=1,N9
          CALL RMOVE(MFE(9),9)
          IF(ATRIB(2).EQ.1) N99=N99-1
          CALL FILEM(1)
    3 CONTINUE
      N9=N99
    4 K=NHT-N9
C
C**** PREDICT START OF LOADING OF WAGONS FOR EACH HARVESTER AVAILABLE
C
C**** CHECK QUEUE OF FIELD TRACTORS
      IF(NNQ(5)) 301,220,210
  210 IF(NNQ(5).GT.NNQ(2)) GO TO 211
      N=NNQ(5)
      GO TO 212
  211 N=NNQ(2)
  212 IF(N.EQ.0) GO TO 220
```

```
      DO 215 I=1,N
C**** REMOVE N WAGONS FROM Q2 AND A FIELD TRACTOR FROM Q5
      CALL RMOVE(MFE(2),2)
      TIQE=TNOW-ATRIB(3)
      CALL COLCT(TIQE,2)
      CALL RMOVE(MFE(5),5)
      N9=INT(ATRIB(9))
      BUSFT(N9)=1.0
      CALL TIMST(BUSFT(N9),TNOW,(2+N9))
      IF(K.GT.0) GO TO 214
C**** SCHEDULE ARRIVAL OF FIELD TRACTOR AND EMPTY WAGON AT HARVESTER
      ATRIB(1)=TNOW+ERLNG(5,1)/60.0+PPARM(8,3)/60.0
      ATRIB(2)=4.0
      CALL FILEM(1)
      GO TO 215
  214 ATRIB(1)=TNOW+ERLNG(5,1)/60.0+PPARM(8,3)/60.0
      ATRIB(2)=2.0
      CALL FILEM(1)
      K=K-1
  215 CONTINUE
C
C**** CHECK NUMBER OF FULL WAGONS AND DISPATCH A TRIP IF A
C**** COMPLEMENT IS AVAILABLE
C
  220 N11=INT(ATRIB(11))
      IF(NNQ(3).GE.N11) GO TO 221
      N10=INT(ATRIB(10))
      BUSRT(N10)=0.0
      CALL TIMST(BUSRT(N10),TNOW,(4+N10))
      RETURN
C
C**** SINCE NNQ(3).GT.N11, DISPATCH TRIP OF FULL WAGONS TO FACTORY
C
  221 DO 222 I=1,N11
          CALL RMOVE(MFE(3),3)
          TIQF=TNOW-ATRIB(4)
          CALL COLCT(TIQF,3)
  222 CONTINUE
      CALL RMOVE(MFE(4),4)
      ATRIB(5)=TNOW+3.0
      ATRIB(2)=5.0
C**** PREDICT ARRIVAL TIME AT FACTORY
C
      ATRIB(1)=ATRIB(5)+(PPARM(9,NNRUN)/RNORM(2,2))*60.0
      CALL FILEM(1)
      RETURN
C
C**** SHUT DOWN OPERATIONS FOR TODAY
C
  250 ATRIB(1)=TNOW+10.0
      ATRIB(2)=7.0
      CALL FILEM(1)
      N10=INT(ATRIB(10))
C
C**** SET ROAD TRACTOR IDLE
C
      BUSRT(N10)=0.0
      CALL TIMST(BUSRT(N10),TNOW,(4+N10))
      GO TO 302
C
  300 CALL ERROR(1)
  301 CALL ERROR(2)
  302 RETURN
      END
```

```
C****
      SUBROUTINE STLD
C
C=====================================================================
C     THIS SUBROUTINE SIMULATES THE START OF LOADING
C       1) THE IDENTITY OF THE FIELD TRACTOR IS RECORDED AS N9
C       1) THE HARVESTER IS COMBINED WITH THE ENTITIES INVOLVED
C          THE LOADING PROCESS
C       3) THE END OF LOADING IS PREDICTED
C=====================================================================
C
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/ ISC,QUOTA,AMOUNT,ENTM,BREAK,STTM,NRT,NHT,NFT,NWG,
     1CAP,BUSHT(2),BUSFT(4),BUSRT(6),TIQE,TIQF,RTRIP,SHFND,WKTM
C**** RECORD IDENTITY OF FIELD TRACTOR
      N9=ATRIB(9)
C
C**** HARVESTER IS COMBINED WITH THE ENTITIES IN THE LOADING PROCESS
      CALL RMOVE(MFE(6),6)
      ATRIB(9)=N9
      N8=INT(ATRIB(8))
      BUSHT(N8)=1.0
      CALL TIMST(BUSHT(N8),TNOW,N8)
C**** PREDICT END OF LOADING BY SAMPLING THE GAMMA DISTRIBUTION
C**** OF THE LOAD TIME
      ATRIB(1)=TNOW+GAMA(1,1)+PPARM(8,1)
      ATRIB(2)=3.0
      CALL FILEM(1)
      RETURN
      END
```

```
C****
      SUBROUTINE NDLD
C=====================================================================
C     THIS SUBROUTINE SIMULATES THE ACTIVITIES AT THE FIELD
C     AT THE END OF LOADING
C=====================================================================
C
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/ ISC,QUOTA,AMOUNT,ENTM,BREAK,STTM,NRT,NHT,NFT,NWG,
     1CAP,BUSHT(2),BUSFT(4),BUSRT(6),TIQE,TIQF,RTRIP,SHFND,WKTM
      COMMON /GCOM5/ IIEVT,IISED(6),JJBEG,JJCLR,MMNIT,MMON,NNAME(3),NNOF
     1I,NNDAY,NNPT,NNSET,NNPRJ,NNPRM,NNRNS,NNRUN,NNSTR,NNYR,SSEED(6)
      COMMON /UCOM2/ DWN,SMILE
C
C**** RECORD IDENTIFICATION OF FIELD TRACTOR AND HOLD IN FILE 5
    5 N9=INT(ATRIB(9))
      CALL FILEM(5)
C**** PREDICT TIME OF ARRIVAL OF FULL WAGON IN QUEUE OF
C**** FULL WAGONS (FILE 3)
C
      ATRIB(4)=TNOW+ERLNG(6,1)/60.0+PPARM(8,3)/60.0
      A=ATRIB(4)
      CALL FILEM(3)
C
C**** CHECK NUMBER OF WAGON AND FIELD TRACTOR COMBINATIONS WAITING
C**** FOR LOADING. IF NUMBER.GT.O SCHEDULE STLD FOR ONE
C
      IF(NNQ(8)) 301,20,10
   10 CALL RMOVE(MFE(8),8)
      TIQW=TNOW-ATRIB(14)
      CALL COLCT(TIQW,4)
      ATRIB(1)=TNOW+0.15
      ATRIB(2)=2.0
      CALL FILEM(1)
C**** CHECK NUMBER OF EMPTY WAGONS AT FIELD AND SET UP
C**** ARRIVAL OF ONE AT HARVESTER IF NUMBER.GT.O
C
      IF(NNQ(2).EQ.0) GO TO 30
      CALL RMOVE(MFE(2),2)
      TIQE=TNOW-ATRIB(3)
      CALL COLCT(TIQE,2)
      CALL RMOVE(MFE(5),5)
      ATRIB(1)=TNOW+ERLNG(7,1)+PPARM(8,4)
C
C**** TEST TO CHECK THAT THE CYCLE TIME IS NOT LESS THAN
C**** THE TRIP TIME TO THE QUEUE OF FULL WAGONS
C
      IF(ATRIB(1).GT.A) GO TO 15
      ATRIB(1)=ATRIB(1)+A-TNOW
   15 ATRIB(2)=4.0
      CALL FILEM(1)
      GO TO 201
C
C**** CHECK NUMBER OF EMPTY WAGONS AT FIELD AND SCHEDULE STLD
C**** IF NUMBER.GT.O
C
   20 IF(NNQ(2)) 302,30,25
   25 CALL RMOVE(MFE(2),2)
      TIQE=TNOW-ATRIB(3)
      CALL COLCT(TIQE,2)
      CALL RMOVE(MFE(5),5)
      ATRIB(1)=TNOW+ERLNG(7,1)+PPARM(8,4)
      IF(ATRIB(1).GT.A) GO TO 26
      ATRIB(1)=ATRIB(1)+A-TNOW
   26 ATRIB(2)=2.0
      CALL FILEM(1)
      GO TO 201
C
C**** IF NUMBER OF EMPTY WAGONS AT FIELD.EQ.O, SET FIELD
C**** TRACTOR IDLE AND COLLECT STATS.
C
   30 BUSFT(N9)=0.0
      CALL TIMST(BUSFT(N9),TNOW,(2+N9))
C**** RECORD ID OF HARVESTER AND HOLD IN FILE 6
      N8=INT(ATRIB(8))
```

```
      BUSHT(N8)=0.0
      CALL TIMST(BUSHT(N8),TNOW,N8)
      CALL FILEM(6)
  201 N11=INT(ATRIB(11))
C
C**** IF THERE IS A COMPLEMENT OF FULL WAGONS AND A ROAD TRACTOR
C**** AVAILABLE, DISPATCH A TRIP TO THE FACTORY
C
      IF(NNQ(3).GE.N11.AND.NNQ(4).GT.0) GO TO 202
      RETURN
  202 DO 203 I=1,N11
          CALL RMOVE(MFE(3),3)
          TIQF=TNOW-ATRIB(4)
          IF(TIQF)1,2,2
    1     TIQF=0.0
    2     CALL COLCT(TIQF,3)
  203 CONTINUE
C**** REMOVE A ROAD TRACTOR FROM QUEUE OF ROAD TRACTORS, Q4
      CALL RMOVE(MFE(4),4)
C**** SET TIME OF DEPARTURE FROM FIELD
      ATRIB(5)=TNOW+5.0
C**** PREDICT TIME OF ARRIVAL AT FACTORY
      ATRIB(1)=ATRIB(5)+(PPARM(9,NNRUN)/RNORM(2,2))*60.0
      ATRIB(2)=5.0
      CALL FILEM(1)
      N10=INT(ATRIB(10))
C**** SET ROAD TRACTOR BUSY AND COLLECT STATS,
      BUSRT(N10)=1.0
      CALL TIMST(BUSRT(N10),TNOW,(4+N10))
      RETURN
C
  300 CALL ERROR(3)
  301 CALL ERROR(88)
  302 CALL ERROR(222)
      RETURN
      END
```

```
C****
      SUBROUTINE ARHTR
C=======================================================================
C****
C     THIS SUBROUTINE SIMULATES THE ARRIVAL OF A FIELD TRACTOR
C     PULLING AN EMPTY WAGON AT THE HARVESTER WHEN IT IS BUSY.
C     THE VEHICLE COMBINATION IS HELD IN FILE 8
C=======================================================================
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/ ISC,QUOTA,AMOUNT,ENTM,BREAK,STTM,NRT,NHT,NFT,NWG,
     1CAP,BUSHT(2),BUSFT(4),BUSRT(6),TIQE,TIQF,RTRIP,SHFND,WKTM
C
C**** PUT VEHICLE COMBINATION INTO FILE 8
      ATRIB(14)=TNOW
      CALL FILEM(8)
      RETURN
      END
```

```
C****
      SUBROUTINE ARFCT
C=====================================================================
C     THIS SUBROUTINE SIMULATES THE ARRIVAL OF A TRANSPORT UNIT
C     AT THE FACTORY AND PREDICTS ITS FACTORY RESIDENCE TIME
C=====================================================================
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/ ISC,QUOTA,AMOUNT,ENTM,BREAK,STTM,NRT,NHT,NFT,NWG,
     1CAP,BUSHT(2),BUSFT(4),BUSRT(6),TIQE,TIQF,RTRIP,SHFND,WKTM
C
      ATRIB(6)=TNOW
C**** PREDICT UNITS RESIDENCE TIME AT THE FACTORY
C
      ATRIB(1)=TNOW+GAMA(3,3)+PPARM(8,2)
      ATRIB(2)=6.0
      CALL FILEM(1)
      ATRIB(1)=ATRIB(1)-TNOW
      CALL HISTO(ATRIB(1),1)
      RETURN
      END
```

```
C****
C
      SUBROUTINE DPFCT
C=====================================================================
C     THIS SUBROUTINE SIMULATES THE DEPARTURE OF A TRANSPORT UNIT
C     FROM THE FACTORY, PREDICTS ITS ARRIVAL AT THE FIELD, RECORDS
C     THE ARRIVAL IN FILE 7, AND LABELS THE UNIT AS HAVING DELIVERED
C     ITS LOAD:--(ATRIB(12)=1)
C=====================================================================
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/ ISC,QUOTA,AMOUNT,ENTM,BREAK,STTM,NRT,NHT,NFT,NWG,
     1CAP,BUSHT(2),BUSFT(4),BUSRT(6),TIQE,TIQF,RTRIP,SHFND,WKTM
      COMMON /GCOM5/ IIEVT,IISED(6),JJBEG,JJCLR,MMNIT,MMON,NNAME(3),NNOF
     1I,NNDAY,NNPT,NNSET,NNPRJ,NNPRM,NNRNS,NNRUN,NNSTR,NNYR,SSEED(6)
      COMMON /UCOM2/ DWN,SMILE
C
C**** SET TIME OF DEPARTURE FROM FACTORY
C
      ATRIB(7)=TNOW
C**** LABEL UNIT AS HAVING DELIVERED ITS LOAD
C
      ATRIB(12)=1.0
C**** PREDICT THE ARRIVAL OF THE TRANSPORT UNIT, WHICH IS JUST
C**** LEAVING THE FACTORY, BACK AT THE FIELD
C
      ATRIB(1)=TNOW+(PPARM(9,NNRUN/RNORM(4,2))*60.0)
      ATRIB(2)=1.0
      CALL FILEM(1)
C**** STORE INFORMATION ON ROAD TRACTOR, PROCESSED AT FACTORY,
C**** IN FILE 7
      CALL FILEM(7)
      RETURN
      END
```

```
C****
      SUBROUTINE SHTDN
C=====================================================================
C     THIS SUBROUTINE PROCESSES ALL SCHEDULED EVENTS AND RETURNS
C     THE ENTITIES ASSOCIATED WITH EACH TO THEIR RESPECTIVE FILES
C=====================================================================
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/ ISC,QUOTA,AMOUNT,ENTM,BREAK,STTM,NRT,NHT,NFT,NWG,
     1CAP,BUSHT(2),BUSFT(4),BUSRT(6),TIQE,TIQF,RTRIP,SHFND,WKTM
      COMMON /UCOM2/ DWN,SMILE
      COMMON /UCOM4/ LRPRT,N77,NSHF,NDAY,NEST,NRPRT
C
C**** SET SYSTEM STATUS MARKER
C
      DWN=1.0
      IF(NRPRT.EQ.1) GO TO 20
      GO TO 730
C**** CHECK QUEUE OF FIELD TRACTOR AND EMPTY WAGON COMBINATIONS
C
   20 IF(NNQ(8).GT.0) GO TO 240
      GO TO 5
C
C**** PUT EMPTY WAGONS AND FIELD TRACTORS WAITING IN THE FIELD INTO
C**** THEIR RESPECTIVE FILES
C****
  240 N=NNQ(8)
      DO 241 I=1,N
         CALL RMOVE(MFE(8),8)
         CALL FILEM(2)
         CALL FILEM(5)
         N9=ATRIB(9)
         BUSFT(N9)=0.0
         CALL TIMST(BUSFT(N9),TNOW,(2+N9))
  241 CONTINUE
C
C**** CLEAR THE "FUTURE EVENTS" FILE (FILE 1) AND SORT OUT
C**** THE ENTITIES
C
    5 N=NNQ(1)
      NK=1
   10 CALL RMOVE(MFE(1),1)
      N2=INT(ATRIB(2))
      GO TO (100,200,300,200,500,500,102,102),N2
  100 RTRIP=ATRIB(1)-ATRIB(5)
      CALL COLCT(RTRIP,1)
      ATRIB(12)=0.0
      N11=INT(ATRIB(11))
      DO 101 I=1,N11
         CALL FILEM(2)
  101 CONTINUE
      N10=INT(ATRIB(10))
      BUSRT(N10)=0.0
      CALL TIMST(BUSRT(N10),ATRIB(1),(4+N10))
      CALL FILEM(4)
  102 NK=NK+1
      IF(NK.LE.N) GO TO 10
      GO TO 700
  200 CALL FILEM(2)
      N9=INT(ATRIB(9))
      BUSFT(N9)=0.0
      CALL TIMST(BUSFT(N9),TNOW,(2+N9))
      CALL FILEM(5)
      GO TO 102
  300 CALL FILEM(3)
      N9=INT(ATRIB(9))
      BUSFT(N9)=0.0
      CALL TIMST(BUSFT(N9),(TNOW+2.0),(2+N9))
      CALL FILEM(5)
  301 N8=INT(ATRIB(8))
      BUSHT(N8)=0.0
      CALL TIMST(BUSHT(N8),(TNOW+2.0),N8)
      CALL FILEM(6)
      IF(ISC.EQ.1) GO TO 102
      AMOUNT=AMOUNT-CAP
      CALL FILEM(2)
```

```
      GO TO 102
  500 IF(SHFND.LT.ENTM) GO TO 502
      CALL FILEM(7)
      N11=INT(ATRIB(11))
      DO 501 I=1,N11
          CALL FILEM(2)
  501 CONTINUE
      AMOUNT=AMOUNT-CAP
      CALL FILEM(4)
      N10=INT(ATRIB(10))
      BUSRT(N10)=0.0
      CALL TIMST(BUSRT(N10),TNOW,(4+N10))
      GO TO 102
  502 CALL FILEM(9)
      GO TO 102
C
C**** THIS SEGMENT OF CODE COLLECTS DATA ON THE OPERATIONS
C**** UP TO THIS POINT FOR THE DESIRED REPORT
C
  700 IF(NRPRT.EQ.1) GO TO 710
      GO TO 720
  710 CALL REPRT
C
C**** THIS SEGMENT OF CODE SETS UP FOR THE START OF NEXT SHIFT

  720 IF(NNQ(9).GT.0) GO TO 205
      GO TO 9
  205 N=NNQ(9)
      DO 6 I=1,N
          CALL RMOVE(MFE(9),9)
          CALL FILEM(1)
    6 CONTINUE
      IF(NRPRT.EQ.1) GO TO 9
      AFTOTA=N*CAP
      WRITE(6,8) AFTOTA
    8 FORMAT(//,20("*"),"AFTER-SHIFT-END DELIVERIES =  ",
     1F6.2,20("*"))
C**** IF QUOTA IS SATISFIED OR END OF SHIFT TIME HAS COME, SUSPEND
C**** OPERATIONS UNTIL NEXT DAY
    9 IF(AMOUNT.LE.0) GO TO 3
      IF(TNOW.GE.ENTM) GO TO 3
C**** SET START OF NEXT SHIFT
      ATRIB(1)=SHFND+BREAK
C**** SCHEDULE END OF NEXT SHIFT
      SHFND=ATRIB(1)+WKTM
      GO TO 4
C**** SCHEDULE START OF SHIFT ON THE NEXT DAY
    3 ATRIB(1)=STTM+1440
      STTM=ATRIB(1)
      AMOUNT=QUOTA+AMOUNT
C**** SCHEDULE END TIME ON NEXT DAY
      ENTM=ENTM+1440
      SHFND=STTM+WKTM
    4 ATRIB(2)=8.0
      CALL FILEM(1)
C
C**** FIX TIME OF NEXT SHUTDOWN EVENT
C
      ATRIB(1)=SHFND
      ATRIB(2)=7.0
      CALL FILEM(1)
      RETURN
  730 CALL ERROR(30)
      RETURN
      END
```

```
C****
      SUBROUTINE DSTART(I,K)
C=====================================================================
C     THIS SUBROUTINE RESETS THE TIME OF ARRIVAL IN QUEUES 2 AND 3
C     AT THE START OF EACH SHIFT
C=====================================================================
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
C
      N=NNQ(I)
      IF(N.EQ.0) RETURN
      DO 1 J=1,N
      CALL RMOVE(MFE(I),I)
          ATRIB(K)=TNOW
          CALL FILEM(I)
    1 CONTINUE
      RETURN
      END
```

```
C****
      SUBROUTINE STRTUP
C=====================================================================
C     THIS SUBROUTINE SIMULATES THE START UP ACTIVITIES AT THE START
C     OF EACH SHIFT AND RESETS SPECIAL MARKERS USED IN THE PROGRAM
C=====================================================================
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /GCOM5/ IIEVT,IISED(6),JJBEG,JJCLR,MMNIT,MMON,NNAME(3),NNOF
     1I,NNDAY,NNPT,NNSET,NNPRJ,NNPRM,NNRNS,NNRUN,NNSTR,NNYR,SSEED(6)
      COMMON /UCOM1/ ISC,QUOTA,AMOUNT,ENTM,BREAK,STTM,NRT,NHT,NFT,NWG,
     1CAP,BUSHT(2),BUSFT(4),BUSRT(6),TIQE,TIQF,RTRIP,SHFND,WKTM
      COMMON /UCOM2/ DWN,SMILE
      COMMON /UCOM4/ LRPRT,N77,NSHF,NDAY,NEST,NRPRT
C
C**** RESET SYSTEM STATUS MARKER
C
      DWN=0.0
C
C**** RESET GASPIV DATA STORAGE ARRAYS
C
      CALL CLEAR
C
C**** RESET TIME OF ARRIVAL OF VEHICLES IN QUEUES 2,3 AND4
C
      CALL DSTART(2,3)
      CALL DSTART(3,4)
C
C**** SET UP LOADING OPERATION FOR EACH COMBINE HARVESTER AVAILABLE
C
      N6=NNQ(6)
      IF(N6.EQ.0) GO TO 500
      IF(NNQ(2).EQ.0) GO TO 101
      DO 100 I=1,N6
         CALL RMOVE(MFE(2),2)
         TIQE=0.0
         CALL COLCT(TIQE,2)
         CALL RMOVE(MFE(5),5)
         N9=INT(ATRIB(9))
         BUSFT(N9)=1.0
         CALL TIMST(BUSFT(N9),TNOW,(2+N9))
   10    CALL RMOVE(MFE(6),6)
         N8=INT(ATRIB(8))
         BUSHT(N8)=1.0
         ATRIB(1)=TNOW+GAMA(1,1)+PPARM(8,1)
         ATRIB(2)=3.0
         CALL FILEM(1)
         CALL TIMST(BUSHT(N8),ATRIB(1),N8)
  100 CONTINUE
C
C**** DISPATCH AS MANY TRIPS TO THE FACTORY AS THERE ARE COMPLEMENTS
C**** OF 2 WAGONS PLUS A ROAD TRACTOR AVAILABLE
C
  101 IF(NNQ(4)) 501,205,200
  200 N=NNQ(3)
      N11=INT(ATRIB(11))
C**** CALCULATE NUMBER OF 2-WAGON TRAINS AVAILABLE
      K=N/N11
      IF(K) 300,205,102
  102 IF(NNQ(4).LT.K) GO TO 201
      K1=K
      GO TO 202
  201 K1=NNQ(4)
  202 DO 204 I=1,K1
        DO 203 J=1,N11
         CALL RMOVE(MFE(3),3)
         TIQF=0.0
         CALL COLCT(TIQF,3)
  203   CONTINUE
         CALL RMOVE(MFE(4),4)
         ATRIB(5)=TNOW+3.0
         ATRIB(1)=ATRIB(5)+(PPARM(9,NNRUN)/RNORM(2,2))*60.0
         ATRIB(2)=5.0
         CALL FILEM(1)
         N10=INT(ATRIB(10))
         BUSRT(N10)=1.0
```

```
          CALL TIMST(BUSRT(N10),TNOW,(4+N10))
  204 CONTINUE
C
C**** IF NFT.GT.NHT, SET UP FIELD TRACTOR AND EMPTY WAGON COMBINATIONS
C**** TO WAIT
C
  205 IF(NNQ(5).EQ.0) GO TO 300
      IF(NNQ(2).EQ.0) GO TO 300
      IF(NNQ(2).LT.NNQ(5)) GO TO 310
      K=NNQ(5)
      GO TO 311
  310 K=NNQ(2)
  311 DO 312 I=1,K
          CALL RMOVE(MFE(2),2)
      TIQE=0.0
      CALL COLCT(TIQE,2)
          CALL RMOVE(MFE(5),5)
          N9=INT(ATRIB(9))
          BUSFT(N9)=1.0
          CALL TIMST(BUSFT(N9),TNOW,(2+N9))
          ATRIB(1)=TNOW+ERLNG(5,1)/60.0+PPARM(8,3)/60.0
          ATRIB(2)=4.0
          CALL FILEM(1)
  312 CONTINUE
  300 IF(NRPRT.EQ.1) GO TO 502
      WRITE(6,1) AMOUNT,TNOW
    1 FORMAT(/,T20,"THE QUOTA FOR TODAY IS ",F10.4,5X,"AT",E10.4)
      IF(LRPRT) 600,502,202
  600 CALL PRNTQ(0)
      GO TO 502
  305 CALL ERROR(10)
  500 CALL ERROR(5)
  501 CALL ERROR(6)
  502 RETURN
      END
```

```
C****
C****
      SUBROUTINE REPRT
C======================================================================
C     THIS SUBROUTINE IS USED TO COMPILE DATA FOR A REPORT AT THE END
C     OF EACH SIMULATION RUN. EACH RUN SIMULATES 12 CONSECUTIVE
C     SHIFTS (OR ONE WEEK'S OPERATION.
C======================================================================
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /GCOM5/ IIEVT,IISED(6),JJBEG,JJCLR,MMNIT,MMON,NNAME(3),NNOF
     1I,NNDAY,NNPT,NNSET,NNPRJ,NNPRM,NNRNS,NNRUN,NNSTR,NNYR,SSEED(6)
      COMMON /GCOM6/ EENQ(100),IINN(100),KKRNK(100),MMAXQ(100),
     1QQTIM(100),SSOBV(25,5),SSTPV(25,6),VVNQ(100)
      COMMON /UCOM1/ ISC,QUOTA,AMOUNT,ENTM,BREAK,STTM,NRT,NHT,NFT,NWG,
     1CAP,BUSHT(2),BUSFT(4),BUSRT(6),TIQE,TIQF,RTRIP,SHFND,WKTM
      COMMON /UCOM3/ JOT,KL
      COMMON /UCOM4/ LRPRT,N77,NSHF,NDAY,NEST,NRPRT
      COMMON /UCOM5/ TAB(21,20),KARRAY(21,20),SUM(21),NSUM(21)
C
      KL=KL+1
      IF(N77.GT.0) GO TO 10
      N77=NNQ(7)
      GO TO 20
   10 N77=NNQ(7)-N77
   20 NSHF=NSHF+1
      KARRAY(1,KL)=NDAY
      KARRAY(2,KL)=NSHF
      DO 30 J=1,4
          IF(SSOBV(J,3).GT.0.0) GO TO 29
      GO TO 30
   29     TAB(2+J,KL)=SSOBV(J,1)/SSOBV(J,3)
          SUM(2+J)=TAB(2+J,KL)+SUM(2+J)
   30 CONTINUE
      DO 40 J=1,10
      IF(SSTPV(J,3)-TTCLR.LE.0) GO TO 31
      XS=SSTPV(J,1)+SSTPV(J,6)*(TNOW-SSTPV(J,3))
      XT=TNOW-TTCLR
          TAB(6+J,KL)=XS/XT
          GO TO 32
   31     TAB(6+J,KL)=1.0
   32     SUM(6+J)=TAB(6+J,KL)+SUM(6+J)
   40 CONTINUE
      KARRAY(17,KL)=N77
      NSUM(17)=NSUM(17)+KARRAY(17,KL)
      KARRAY(18,KL)=NNQ(9)
      NSUM(18)=NSUM(18)+KARRAY(18,KL)
      KARRAY(19,KL)=NNQ(2)
      NSUM(19)=NSUM(19)+KARRAY(19,KL)
      KARRAY(20,KL)=NNQ(3)
      NSUM(20)=NSUM(20)+KARRAY(20,KL)
      B=N77
      TAB(21,KL)=B*CAP
      SUM(21)=SUM(21)+TAB(21,KL)
      N77=NNQ(7)
      IF(SHFND.GE.ENTM.OR.AMOUNT.LE.0) GO TO 60
      GO TO 70
   60 NDAY=NDAY+1
      NSHF=0
   70 RETURN
      END
```

```
C****
C****
      SUBROUTINE OTPUT
C=================================================================
C     THIS SUBROUTINE IS USED TO PRINT OUT A TABLE OF SUMMARIZED DATA
C     AT THE END OF EACH SIMULATION RUN.
C=================================================================
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,NCRDR,N
     1NAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),TNOW,TTBEG
     2,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /GCOM5/ IIEVT,IISED(6),JJBEG,JJCLR,MMNIT,MMON,NNAME(3),NNOF
     1I,NNDAY,NNPT,NNSET,NNPRJ,NNPRM,NNRNS,NNRUN,NNSTR,NNYR,SSEED(6)
      COMMON /GCOM6/ EENQ(100),IINN(100),KKRNK(100),MMAXQ(100),
     1QQTIM(100),SSOBV(25,5),SSTPV(25,6),VVNQ(100)
      COMMON /UCOM1/ ISC,QUOTA,AMOUNT,ENTM,BREAK,STTM,NRT,NHT,NFT,NWG,
     1CAP,BUSHT(2),BUSFT(4),BUSRT(6),TIQE,TIQF,RTRIP,SHFND,WKTM
      COMMON /UCOM3/ JOT,KL
      COMMON /UCOM4/ LRPRT,N77,NSHF,NDAY,NEST,NRPRT
      COMMON /UCOM5/ TAB(21,20),KARRAY(21,20),SUM(21),NSUM(21)
C
      IF(NRPRT.NE.1) RETURN
      NC=KL
      Z=KL
      KILOM=INT(PPARM(9,NNRUN))
      WRITE(6,90)
      WRITE(6,5) NEST,KILOM,QUOTA,NWG,NHT,NFT,NRT
      WRITE(6,10)  (KARRAY(1,J),J=1,NC)
      WRITE(6,15)  (KARRAY(2,J),J=1,NC)
      AVE=SUM(3)/Z
      WRITE(6,20)  (TAB(3,J),J=1,NC),AVE
      AVE=SUM(4)/Z
      WRITE(6,25)  (TAB(4,J),J=1,NC),AVE
      AVE=SUM(5)/Z
      WRITE(6,30)  (TAB(5,J),J=1,NC),AVE
      AVE=SUM(6)/Z
      IF(NFT.GT.1) WRITE(6,35)  (TAB(6,J),J=1,NC),AVE
  100 DO 21 I=1,NHT
        AVE=SUM(6+I)/Z
   21 WRITE(6,40) I,(TAB(6+I,J),J=1,NC),AVE
      DO 31 I=1,NFT
        AVE=SUM(8+I)/Z
   31 WRITE(6,45) I,(TAB(8+I,J),J=1,NC),AVE
      DO 41 I=1,NRT
        AVE=SUM(10+I)/Z
   41 WRITE(6,50) I,(TAB(10+I,J),J=1,NC),AVE
  200 NAVE=NSUM(17)/NC
      WRITE(6,55)  (KARRAY(17,J),J=1,NC),NAVE
      NAVE=NSUM(18)/NC
      WRITE(6,60)  (KARRAY(18,J),J=1,NC),NAVE
      NAVE=SUM(19)/NC
      WRITE(6,65)  (KARRAY(19,J),J=1,NC),NAVE
      NAVE=NSUM(20)/NC
      WRITE(6,70)  (KARRAY(20,J),J=1,NC),NAVE
  300 AVE=SUM(21)/Z
      WRITE(6,75)  (TAB(21,J),J=1,NC),AVE
   90 FORMAT(T20,80("*"),/,T20,"*",T50,"END OF SHIFT REPORT",T99,"*",
     1/T20,80("*"))
      WRITE(6,80)
   80 FORMAT(/,   T5,"NDAY = DAY NUMBER",T60,"URT# = UTILIZATION OF ROAD
     1 TRACTOR #"/,T5,"NSHF = SHIFT NUMBER",T60,"TRPTS = NUMBER OF",
     2" TRIPS COMPLETED THIS SHIFT"/T5, "ATRPT = AVE TRIP TIME",T60,
     3"TRPIT = NUMBER OF TRIPS IN TRANSIT AT END OF SHIFT"/T5,"TIQE =
     4 AVE TIME AN EMPTY WAGON WAITS AT THE FIELD ",T60,"NEWG = NUMBER",
     5" OF EMPTY WAGONS AT FIELD"/T12,"TO BE LOADED",T60,"NFWG =
     6NUMBER OF FULL WAGONS AT FIELD"/T5,"TIQF = AVE TIME A FULL WAGON
     7WAITS AT THE FIELD")
      WRITE(6,85)
   85 FORMAT(T5,"UHT# = UTILIZATION OF HARVESTER #",T60,"TNNESD =
     1TOTAL TONNES DELIVERED"/T5,"UFT# = UTILIZATION OF FIELD TRACTOR
     2#")
    5 FORMAT(//,T10,"ESTATE NO.",T20,"=",I3,T45,"DISTANCE TO FACTORY = "
     1,I3," KILOMETERS",T85,"DAILY QUOTA = ",F6.0," TONNES",//,T45,
     2"EQUIPMENT COMBINATION",T60,4("*",I3))
   10 FORMAT(/1X,"NDAY ",20I5)
   15 FORMAT(/1X,"NSHF ",20I5," MEANS")
   20 FORMAT(/1X,"ATRPT ",21F5.1)
   25 FORMAT(/1X,"TIQE ",21F5.1)
```

```
30 FORMAT(/1X,"TIOF ",21F5.1)
35 FORMAT(/1X,"TIOW ",21F5.1)
40 FORMAT(/1X,"UHT",I1,1X,21F5.1)
50 FORMAT(/1X,"URT",I1,1X,21F5.1)
45 FORMAT(/1X,"UFT",I1,1X,21F5.1)
55 FORMAT(/1X,"TRPTS",1X,21I5)
60 FORMAT(/1X,"TRPIT",1X,21I5)
65 FORMAT(/1X,"NEWG",1X,21I5)
70 FORMAT(/1X,"NFWG",1X,21I5)
75 FORMAT(/1X,"TNNESD",1X,21F5.0)
   RETURN
   END
```

NON-GASPIV DATA INPUT:

```
  ISC = 1
  NWG = 8
  NHT = 1
  NFT = 2
  NRT = 2
 NEST = 1
QUOTA =     200.00 TONNES
  CAP =      10.00 TONNES

  ENT =     660.00 MINS
BREAK =      60.00 MINS
 WKTM =     300.00 MINS
 NRPRT = 1
 LRPRT = 1
```

```
                              SIMULATION PROJECT NUMBER 100  BY  W. HARVEY

                              DATE 10/ 15/   82       RUN NUMBER    1 OF    1
                              LLSUP=00000000001101    GASP IV VERSION 23JUN73

NNCLT=     4    NNSTA=    10    NNHIS=     1    NNPRM=     9    NNPLT=     0    NNSTR=     4    NNTRY=   500
NNATR=    14    NNFIL=     9    NNSET= 10000    NNEQD=     0    NNEQS=     0    NFLAG=     0

COLCT NO.  1    LLABC=RTRIP
COLCT NO.  2    LLABC=TIQE
COLCT NO.  3    LLABC=TIQF
COLCT NO.  4    LLABC=TIQW

TIMST NO.  1    LLABT=BUSHT(1)  I.C. =      0.
TIMST NO.  2    LLABT=BUSHT(2)  I.C. =      0.
TIMST NO.  3    LLABT=BUSFT(1)  I.C. =      0.
TIMST NO.  4    LLABT=BUSFT(2)  I.C. =      0.
TIMST NO.  5    LLABT=BUSRT(1)  I.C. =      0.
TIMST NO.  6    LLABT=BUSRT(2)  I.C. =      0.
TIMST NO.  7    LLABT=BUSRT(3)  I.C. =      0.
TIMST NO.  8    LLABT=BUSRT(4)  I.C. =      0.
TIMST NO.  9    LLABT=BUSRT(5)  I.C. =      0.
TIMST NO. 10    LLABT=BUSRT(6)  I.C. =      0.

HISTO NO.  1    LLABH=RT.FCT                    NNCEL=    15    HHLOW=      .1100E+02   HHWID=        5000E+01

KKRNK= (   1)     3       4      13      13      13       6      14       0

IINN = (   1)     3       3       3       3       3       1       1       0

PARAMETER SET     1 =       .6100E+01       0.                  .1545E+02       .2000E+01
PARAMETER SET     2 =       .1274E+02         .6440E+01         .2462E+02       .5890E+01
PARAMETER SET     3 =       .5206E+01       0.                  .1134E+03       .4003E+01
PARAMETER SET     4 =       .2327E+02         .1931E+02         .3218E+02       .4022E+01
PARAMETER SET     5 =       .1570E-01       0.                  .4290E+03       .1877E+01
PARAMETER SET     6 =       .2760E-01       0.                  .3100E+03       .3370E+01
PARAMETER SET     7 =       .5600E-01       0.                  .1023E+03       .1000E+01
PARAMETER SET     8 =       .7870E+01         .6050E+01         .1800E+02       .3200E+01
PARAMETER SET     9 =       .3000E+01         .5000E+01         .8000E+01       .1100E+02

MSTOP=     1    JJCLR=     1    JJBEG=     1    IICRD=     0    TTBEG=     0.           TTFIN=        1440E+05
JJFIL=     4
IISED= 52121          44391           43183           45212
```

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