A FRAMEWORK FOR A DECISION SUPPORT TOOL IN AN AGILE AGRICULTURAL ENVIRONMENT

J. Wium[1*], J van Eeden[2] and J Bekker[3]
[123]Department of Industrial Engineering
University of Stellenbosch, South Africa
wiumjolene@gmail.com[1], jveeden@sun.ac.za[2], jb2@sun.ac.za[3]

Abstract

Supply planning in table grape production is difficult due to long lead times from planting to production with variable yields. Market agility for producers is important due to market volatility while diversified income streams and markets lower a producer's risk. Strategic managers need to ensure market demand match the harvest available through planning cultivar diversity. Tactical managers need to realise the strategy by carefully scheduling harvest and labour plans. These plans are created manually following a cumbersome and sub-optimal process. Operations managers need to implement this plan, however face day-to-day challenges not accounted for in the tactical plan. Agile decision making at tactical and operational levels is needed to work around obstacles in a complex decision space. In this work the characteristics of a decision support system (DSS) needed for tactical and operational decisions are explored and a framework for creating such a DSS based on current literature is provided. A real alternative in the South African fresh produce sector is addressed which requires everyday industrial engineering solutions such as systems design, optimisation, simulation and scheduling.

*Corresponding author

1 INTRODUCTION

The production of fresh fruit is a complex business with many factors to consider. Large agricultural companies are shifting focus from pure crop-driven to a more holistic business approach in order to stay competitive. Locally, South African farmers are faced with policy and resource uncertainties, driving business and investment decisions. This is no different for table grape producers, with approximately 21 000 hectares of table grapes under production, competing for export opportunities [1]. South American countries such as Peru and Chile, with approximately 28 000 and 48 200 hectares of table grape respectively, are direct competitors to local producers [2]. Local producers therefore need to differentiate or focus strategy in order to compete [3].

The subject of this study, Company X, focus on the niche packaging of high-quality grapes to clients with unique product specifications. This is a market differentiation strategy to distinguish them from bulk, lower cost producers. The unique specification of each client allows Company X to increase revenue per hectare, but it also brings in complexity when scheduling the harvest and pack plans for the season. Added to this complexity is the uncertainty of harvest size and date for individual production units. Grapes will ripen at various time periods, which is dependent on weather patterns for that year and the specific cultivar planted. A table grape producer, such as Company X, can have several farms and might be limited by the packing capacity within their business or by the ripeness of the stock. This complexity coupled with sudden changes due to uncertainty results in sub optimal harvest and pack scheduling decisions. Logistical scheduling is therefore needed to pack to maximise revenue for the company and its shareholders.

In this article, the characteristics of a scheduling decision support system (DSS) for table grape harvesting and packing will be explored. Company X requires a comprehensive solution to coordinate many disparate teams. The objectives of this study will therefore be to 1) understand and frame the complex decision environment for Company X during the harvest season; 2) clarify the characteristics and business requirements for a scheduling DSS at company X and then to 3) document the design requirements for a DSS which will be built as part of ongoing research work.

Section 2 of this article will explore the history and characteristics of DSSs. Section 3 will provide details on the methods used to gather data from Company X to determine the design requirements for a DSS. Lastly, sections 4 and 5 will summarise and discuss the requirements for a DSS following end user interviews.

2 BACKGROUND AND LITERATURE REVIEW

In this section, DSSs will be explored through background literature on the types of DSS, the decision-making process in an organisation as well as well as the characteristics that make up a DSS.

2.1 DSS classifications

Decision support systems is a general term used for many different types of software products. Power [4] classifies five types of DSSs based on a previous classification by Alter in 1980 [5]: communication driven DSS, data driven DSS, document driven DSS, knowledge driven DSS and lastly model driven. This classification has since been adopted by the Association for Information Systems Special Interest Group on Decision Support Systems (AIS SIGDSS). Further to this classification, Power identifies three secondary axes that can be used for classification: the intended user, the purpose and lastly the enabling technology. Turban *et al.* [6] notes that most applications are a combination of two or more types of DSSs. Table 1 illustrates the various types of DSSs with their respective use cases, users and components. Section 5 will use this framework to demonstrate the combination of DSSs needed by Company X based on the requirements analysis in section 4.

Table 1: An expanded DSS framework [4]

DSS Type	Target Users	Purpose	Enabling Technology
Communications-driven DSS *(communication)*	Internal, geographically distributed teams	Meetings Collaboration Facilitate information exchange	Video and audio conferencing Cloud storage Online word processing applications
Data Driven-driven DSS *(Database and visualisation systems)*	Managers and staff, partners and suppliers	Query a data warehouse	Relational databases Multidimensional databases
Document-driven DSS *(Document storage)*	Specialists and managers	Search web pages	Search engines, HTML
Knowledge-driven DSS *(Artificial intelligence and knowledge base)*	Internal users and customers	Management advice	Expert systems
Model-driven DSS *(quantitative model)*	Managers and staff, customers and suppliers	Scheduling and forecasting	Linear programming, MS Excel

2.2 DSS and the decision-making process

There are different layers of decision making in an organisation. Operational decisions are routine, well-structured, function specific and internally focussed. These decisions are easier to automate due to the routine and structured nature of the decision. Tactical decisions might have less certainty and not all the decision variables are always known. These decisions are semi structured, also internally focussed, but will incorporate factors from external sources, such as suppliers or clients. Computerized decision support is used for semi-structured decisions and is the reason why DSSs are explored to aid in harvest and processing decisions for Company X. Lastly, strategic decisions are unstructured and could be ad-hoc in nature. These decisions can alter the landscape of an organisation entirely. They are the most difficult to automate and typically make use of ad-hoc models or special studies [7,8].

When considering the decision-making process, Simon's [9] model of decision making is still relevant nearly 30 years after initial publication. The model identifies four phases in the process, namely intelligence, design, choice and implementation. In today's world, Business Intelligence (BI) and big data visualisation can be used to make sense of internal and external data sources during the *intelligence* phase. The *design* phase is used to explore various courses of action, facilitate discussion and provide the users with options. Decision makers need to design possible solutions in this phase based on data in the intelligence phase. The *choice* phase builds on the previous two and focus on choosing the best course of action based on the information available. What-if questions, goal seeking, and scenario testing are often used as examples to help derive the best alternative. Lastly, data from the *implementation* phase is used to determine the success of the decision [6,10].

2.3 Characteristics and capabilities of DSS

Various authors have defined the characteristics of successful DSSs. Table 5 compares the various characteristics mentioned by Alter [5], Delen, Sharma and Turban [6], Power [10] as well as Holsapple and Whinston [11]. The combined attributes described by the above-mentioned authors allude to the type of decisions which DSSs typically support, the decision attributes, the power of the decision maker as well as the DSS infrastructure and architecture. Key themes from these four frameworks include:

- A DSS should support a decision through the phases of decision making mentioned above (intelligence, design, choice and implementation). Power [10] recommends that the DSS provide specific capabilities that support one or all of the four phases of decision making.
- Alter [5] as well as Power [10] agree that a DSS should support a specific decision process. Turban et al. [6], however, recommends that it supports a variety of processes.
- A DSS should improve the effectiveness of a decision. This includes the timing, accuracy and quality of decisions.
- A DSS should support managers at any level of the organisation, but not replace them. A recurring theme in all four studies is that the decision maker/s should be capacitated by the DSS and not made redundant.
- This then also implies that the decision maker should have relative control over the output of the system and have the power and flexibility to change variables that determine this output.
- The user should have easy access to the underlying body of knowledge and raw data contained in the system. This access should be easily manipulated and clearly articulate the underlying business rules.
- Lastly, the DSS can be an independent system that is networked with other systems but contains its own storage and modelling mechanism.

These characteristics provide a framework to use when designing a DSS. Hartono and Holsapple [12] summarises the outcomes of using a DSS by the impact it has on one of the elements described under the acronym PAIRS (productivity, agility, innovation, reputation or satisfaction). It will also help evaluate whether or not this design is successful in practice.

2.4 Designing a DSS

In the previous sub section, the characteristics of a DSS were discussed. In this section the focus will shift to the design of a DSS. This will establish the components needed to describe the DSS for Company X. Given the repeated use and non-technical nature of the end user for this DSS, a special emphasis will be placed on model DSSs, although the final DSS will contain aspects of a combination of DSS [7]. Historically DSSs consisted of a user interface, a database and a model or analytical tool [13]. In recent years, due to changes in technology, network architecture is an essential component of DSSs [14].

An easy to use user interface helps non-technical users to control the input variables and influence the output of the model. A well-designed user interface will empower the user to easily change variables based on the unique situations they face. A poorly designed user interface might eliminate key variables needed for a model and as such disempower the user.

A database is needed to store data generated by the analytical model. Data from underlying systems can be used to feed the model, however a specific history of the DSS needs to be stored in order to build a body of knowledge over time. Input variables and various scenarios can also be stored to reflect on at a later stage.

Models are a simplified representation of reality and capture the essence of the decision through careful deliberation of the parameters involved. Power and Sharda [7] mentions three techniques used in model-driven DSS: 1) Decision analysis, 2) mathematical programming and 3) simulation. Decision analysis involves the quantification of alternative options. This may include decision trees or analytic hierarchy processes. Mathematical programming includes the optimisation of decision criteria given the objectives and constraints of a decision. Simulation involves the recreation of a physical system in a quantitative model. This can then recreate a system electronically when certain parameters are changed and "run" over certain scenarios. The user can then create an imaginary situation and understand the outcomes on the system.

Lastly, it is important to consider the architecture for the DSS as it will typically function in a network of other systems. Data or input variables can be obtained from sub systems. This can be available real-time or more ad-hoc than the DSS will require it posing potential constraints on the end user. It is also important to consider where the tool will be hosted given the infrastructure of the current network and computing requirements of the model. The next section will explain the process of eliciting the requirements for a harvest and production DSS at Company X.

3 METHODS

This study is part of ongoing research to design, build and implement a DSS for harvest and production decisions. In this study the requirements for such a DSS is defined using decision maker requirements. To this end, one on one interviews with key decision makers in Company X were conducted, transcribed and analysed using a six step process of thematic analysis suggested by Braun and Clarke [15,16]. The sample of respondents was selected based on purposive sampling as respondents were selected based on their role and decision-making authority in the company. In total, eight interviewees were selected from operational, tactical and strategic roles namely the production unit manager, packhouse manager, production manager of managers, operations and logistics manager, tactical finance manager, chief marketing manager and strategic finance manager. Interviews were transcribed and coded to extract themes. Relevant themes relating to planning and decision making during the harvest season were extracted and elaborated on in the next section

4 RESULTS

The previous section explained the in-depth decision maker interviews performed at Company X. This section summarises these interviews and illustrates the complexity that exists in the harvest and packing process.

Harvest and pack planning is a year round activity. Figure 1 illustrates the factors that influence harvest and pack decisions. Arrows represent the flow of information between the various plans. Table 2 illustrates the level of authority and frequency of decision of each element in Figure 1. These decision nodes are interconnected and dependent on one another. A recurring issue that emerged from the interviews was the impact one decision node will have on another. A paraphrased quote from one of the interviewees gives an example of the negative impact changing harvest estimates has on the market plan:

> *If one thing changes, it disturbs everything else. (Author translated verbatim)*

Similarly, the changes in market priorities make operational planning difficult. A translated and interpreted quote by one of the respondents who commented on the difficulty in planning:

> *The problem that confuses the pack programs is the changes to the original plan.*
> *It is difficult to plan around (a changing plan).*

The harvest and pack plan bring together operational and tactical activities. The interviews provided insight to the challenges experienced by Company X in planning harvest and pack activities. Each of the elements influencing the harvest and pack plan will be discussed next.

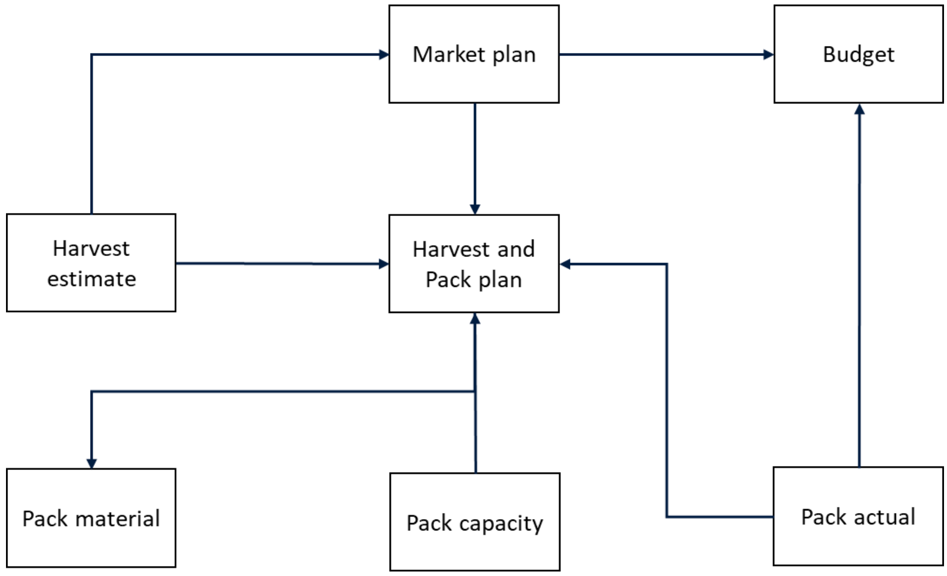

Figure 1: Factors influencing the pack and harvest plan

Table 2: Frequency and decision level of key activities influencing pack and harvest decisions

		decision type		
		strategic	***tactical***	***operational***
frequency	***seasonal***	budget		
	weekly		market plan	harvest estimate
	daily		pack and harvest plan	
			pack material	

4.1 Market plan

The market plan is negotiated with clients throughout the year. It is never finalised and is constantly updated depending on availability and quality of produce, price and the strategic importance of a client. High value produce will be reserved for prime clients after discussion between the marketing and logistics team and the production unit manager. Clients have specific requirements regarding produce which include cultivar (or cultivar group), size, packaging, quality and delivery timeline as influenced by their clients, the consumers. The company needs to adhere to these guidelines as strictly as possible to avoid paying a fine. In the case where these requirements cannot be met internally by Company X, they will in-source from other producers in order to meet the client requirement. Although priority clients get preferential treatment, all client requests must be met as a company policy.

4.2 Harvest estimate

An initial harvest estimate is done approximately six months before harvest based on historic trends. More accurate estimates are done closer to the packing season and weekly during the packing season. This remains a problem to Company X as precision of the estimates is not reflective of reality. The harvest estimate does not reflect third party (in-sourced) produce availability which leaves Company X dependent on strong market relationships to source appropriate produce in time. In season harvest estimates are dependent on the harvest readiness of a production unit and can often be a few days later or earlier than expected. This has a knock-on effect for delivery of produce to clients. Environmental factors, such as rain or extreme temperature conditions, can also affect the outcome of production. The allocation of produce to clients is dependent on the marketing team.

4.3 Pack material

The pack material plan is dependent on the pack and harvest plan. If it changes, the pack material plan should change as well. Pack material is often client-dependent, meaning that material with unique printing is needed for a specific client. Currently, pack material planning is a manual process driven by a single person. Due to the pack and harvest plan being based on a weekly basis, pack material is difficult to adapt to sudden changes in demand or supply within a week. Company X stores and manages all pack material centrally and will distribute to the various pack houses based on the pack plan. This limits the risk of losing pack material in a pack house but adds complexity when scheduling pack activities.

4.4 Pack capacity

Pack capacity is different for each of the pack houses. A theme that emerged 12 times from the interviews was that each pack house has specific constraints. A translated and interpreted quote that refers to daily pack planning illustrates this:

> *Not only should you know the production unit and client requirement, you should also be conscious of the combination of programmes planned on a line.*

Pack house capacity is therefore dependent on (in order of importance):

- station setup: different equipment is used throughout the business. As a result some pack houses can only pack boxes and others only punnets, while some can pack both;
- number of staff: each worker can pack a certain amount per day,
- quality of produce: good quality produce requires less preparation than poor quality produce;
- number of changeovers: changeovers result in downtime whilst new pack material is loaded into the system;
- packaging type: boxes are easier to pack than bags;
- combination of programs being packed: certain station setups cannot pack weights that are too close to one another as the equipment cannot distinguish between the weights and will log an incorrect weight. An example given is a 500g punnet or a 600g punnet. Their relative weights are close and can be logged as under or over weights. This slows the packing time significantly;
- the size of the pack house: worker productivity is dependent on the physical space and energy levels of the workers;
- lastly, management was also given as a factor which might influence worker productivity and flow through the pack house.

4.5 Budget

The budget is a seasonal estimate of income and expenses. It is completed by all production units and the marketing team to simulate capacity, produce availability and market demand. It is used as a reference throughout the year to measure under or over delivery. The budget provides the marketing team with detail such as whether they should sell more or less produce and if they are reaching their financial obligations for the year.

4.6 Pack actual

Pack actual is a historic ledger of everything that has been packed and shipped. It is used to deduct remaining harvest from completed programs daily.

4.7 Pack and harvest plan

The harvest and pack plan is one of the greatest challenges for Company X. It represents the junction between two evolving plans, namely the market plan and the harvest estimate or harvest readiness. It also represents the junction between tactical planning and operational realities. Currently, the pack and harvest plan guide the production managers on which client programs to service at a weekly level. However, realities often result in sub optimal decisions and down time for the pack house. Problems that were identified in this research include among others:

- The tactical planning manager often does not have real-time feedback on the capacities for each pack house;
- Sudden changes in priority from the market can cause confusion regarding priorities;
- Pack house capacities are complicated by pack station setup not accounted for in aggregated capacity data used by the tactical manager. Pack houses have specific station set-ups for the type of packaging being packed. Certain combinations of packaging types cannot be packed together due to the equipment used by the pack house. This is not seen at an aggregated weekly packing level and can result in down time;
- Produce quality and packaging type influence capacity constraints. This changes daily.

The analysis above indicates that the manual process of planning result in sub-optimal decisions over both the tactical and operational functions of the company. Although highly competent people drive the process, an increase in complexity due to the size of the undertaking makes it difficult to keep track of all the factors influencing decision making. Time and availability of information at the correct aggregation level complicate decisions further. The next section discusses a proposed DSS solution that will span over both tactical and operational functions.

5 DISCUSSION

The problems discussed in the previous section illustrate that an integrated solution is needed to aid companywide decisions [17,18]. This section describes the proposed solution for such a system in the context of the characteristics mentioned in section 2.3. Section 2.1 is referenced to classify the proposed DSS provided to its users.

In Table 3, the first column illustrates key business requirement themes which emerged from the interviews at Company X. Due to the complexity and timeliness of a required solution, a combination of DSS types is suggested in the second column. The interdependence of the decision space lends itself more towards a Turban et al.[6] solution where multiple decision functions are supported. The company needs a quicker, more granular way of planning harvest and packing activities to get the best from a harvest period. An optimisation model, which accounts for the multiple and specific constraints, is suggested. To help predict potential bottlenecks or opportunities, a simulation model that uses an underlying body of knowledge to map the system in working or suggested is also recommended. In order to empower users with knowledge of underlying business rules, assumptions and knowledge of the system, a visualisation and continuous monitoring system should be added as recommended by Holsapple and Whinston [11].

Table 3: Proposed solution

Requirement	Category	Solution
Daily scheduling of harvest and pack plans	Frequency	Optimisation
Allocate to predetermined client-block	Constraints	
All programs should be serviced		
Timing: red grapes to be cut in natural light		
Timing: shipment date determines harvest restriction		

Packhouse specific constraints		
Orchard sugar levels must be ready on date of schedule		
Transportation: limited number of cold trucks		
Limit changeover/downtime as much as possible	Penalise	
Exchange rate	Decision variables	
Price		
Labour utilisation		
Transportation distance of grapes: orchard to packhouse		
Transportation distance of grapes		
Outsource grapes: illustrate potential gaps		
Poor quality produce should be excluded		
Include BOM and resource requirement	Output	
Suggestions ready by 10 am		
Forecast suggestion and flag potential bottlenecks or opportunities		Simulation
Compare seasonal and historic versions of harvest estimate Illustrate the rationale behind decisions through data visualisation Give the user easy access to pallet traceability		Visualisation
Continually update norms of harvest activities Continually update norms of pack activities Norms and standards of activities Continually update harvest estimate		Continuous monitoring

Table 4 uses the DSS classification discussed in section 2.1 to categorise this DSS based on the purpose of each solution and the target users. The optimisation model will aid the tactical manager to assign client needs to company produce in a more effective manner. It will also help production managers communicate capacity and prioritise work on a daily level. The simulation model is intended to inform the Tactical manager if a solution is feasible. A data visualisation system will help make information available to the tactical as well as operational staff. Lastly, the continuous monitoring system will inform the models as well as users with insights regarding norms and standards. All four proposed solutions have a specific use case and is made up of two or three types of DSSs. In all four proposed solutions, the system will aid decision makers, and never aim to replace valuable positions. In terms of the PAIRS model proposed by Hartono and Holsapple [12], the proposed DSS will contribute improvements in productivity, agility and reputation to Company X. It will do this by providing relevant information to key decision makers, recommending solutions to complex scheduling problems and verifying plans before being sent out to the operational teams. It will also help the production manager be more effective in communicating restrictions and bottlenecks to the tactical team.

Table 4: DSS classification

Solution	Purpose and users	DSS classification
Optimisation	***Purpose:*** Schedule harvest and pack plans in order to provide a solution to the company. ***Target users:*** Tactical manager and production managers	Model-driven DSS Knowledge-driven DSS
Simulation	***Purpose***: Gives feedback to tactical manager whether a suggested solution is feasible or not. Indicates if potential bottlenecks and non-delivery is a possibility. ***Target users:*** Tactical manager	Model-driven DSS Knowledge-driven DSS Communications-driven

Visualisation	***Purpose*:** Users should have access to underlying assumptions influencing the DSS. The users should also have access to historic and current data in an easily palatable manner. ***Target users:*** Tactical and operations managers, data analysts	Data Driven-driven DSS Communications-driven DSS
Continuous monitoring	***Purpose:*** Continually update and build on a body of internal knowledge based on historic and predicted data. This will form the basis for the optimisation and simulation models. ***Target users***: Tactical manager	Knowledge-driven DSS Communications-driven DSS

This article outlined the requirements for a DSS to be implemented at Company X. It is part of ongoing research where the next steps will include the build of a bespoke DSS based on these requirements. The system will integrate with existing infrastructure and act as a free-standing tool to improve tactical and operational decision-making. This work addresses a real alternative in the South African fresh produce sector which requires everyday industrial engineering solutions such as systems design, optimisation, simulation and scheduling. It stipulates the design and intended implementation of a solution that will make a difference.

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Table 5: Characteristics of DSS

Categories	Characteristic theme	Characteristic	Alter [5]	Holsapple and Whinston [11]	Delen, Sharda, Turban [6]	Power [14]
Decision type	**Repeatability**	DSS are intended for repeated use. A specific DSS may be used routinely or used as needed for ad hoc decision support tasks.				x
	Structure	Support for decision makers in structured and unstructured decisions.			x	
Decision attributes	**Decision dependence**	Support for interdependent and or sequential decisions.			x	
	Decision phases	Support in **all phases** of decision making (intelligence, design, choice and implementation).			x	
		DSS provide specific capabilities that support **one or more tasks** related to decision making, including intelligence and data analysis, identification and design of alternatives, choice among alternatives, and decision implementation.				x
	Decision process	DSS's should be designed to **facilitate a specific decision process**.	x			
		Support for a **variety of decision-making processes and styles**.			x	
		DSS facilitate and support **specific decision-making activities or decision processes**, or both				x
	Effectiveness	DSS are intended to improve the accuracy, timeliness, quality, and overall effectiveness of a specific decision or a set of related decisions.			x	x
Decision maker	**Decision maker: level or structure**	DSS can support decision makers at any level in an organization. They are not intended to replace decision makers.	x		x	x
	Control	The decision maker has complete control over all steps of the decision-making process. A DSS supports and does not replace a decision maker.		x	x	x
	Interactive	Interactive ease of use.		x	x	x
	Flexibility	A DSS should be flexible and respond to the changes in environment experienced by the end user.	x	x	x	
	Modify	End users should be able to modify to a certain extent.		x	x	
System	**Record keeping**	DSS need a recordkeeping capability that can present knowledge on an ad hoc basis in various customized ways as well as in standardized reports.		x		
	Data access	DSS should have capabilities for selecting a desired subset of stored knowledge either for presentation or for deriving new knowledge.		x	x	
	Model / intelligence	DSS must have a body of knowledge.		x		
		Modelling and analysis.			x	
	Architecture	DSS may be independent systems that collect or replicate data from other information systems or subsystems of a larger, more integrated information system.			x	x