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The XXII International Grassland Congress (Revitalising Grasslands to Sustain Our Communities) took place in Sydney, Australia from September 15 through September 19, 2013.
Proceedings Editors: David L. Michalk, Geoffrey D. Millar, Warwick B. Badgery, and Kim M. Broadfoot
Publisher: New South Wales Department of Primary Industry, Kite St., Orange New South Wales, Australia

Opportunities for Improving Livestock Production with e-Management Systems

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Abstract. There is increased interest in hardware and software that can support e-Management for grassland-based livestock industries. Managers of grazing livestock were early adopters of radio frequency identification (RFID) technologies automatically monitoring individual animal performance. Recent developments of remote sensing, automated individual recording and management, location based systems, improved data transfer and technologies that can be used in more extensive grazing systems are providing new opportunities for the development of e-Management systems. There is a need for better data integration and systems that can provide the best available information to enable better decision-making. For greater industry adoption of more integrated e-Management systems, there needs to be a clear economic value. With increased on farm monitoring and the expansion of digital data sources, grazing livestock production systems have the opportunity to expand production efficiency through the implementation of e-Management.

Keywords: e-Management, radio frequency identification, individual performance monitoring.

Introduction

Grazing livestock are a critical component of agricultural throughout the world. As hunter-gatherer communities began the process of domestication, the restriction of animal movement and the use of fences enabled primitive farming practices. Modern grazing systems have been refined but they still use fences to constrain livestock, allowing the animals to harvest their own food in a controlled and 'managed' environment. Management involves moving animals between paddocks, aiming to optimise production by maximising grazing intake (Barrett *et al*. 2001). Grazing livestock systems utilise natural feeding methods, as opposed to machinery that is used to harvest feed which is then provided to animals that are housed (Bailey 1995). Monitoring the pasture, herd or individual animals is used to remove impediments to production, such as disease or nutritional deficiencies (energy, protein and micro nutrients). The complexity of grazing systems is determined by the prevailing environmental conditions, forage production and stocking capacity. Stocking capacity can vary from more than 5 cows per hectare, measured as an adult equivalent (AE) basis, through to in excess of 50 hectares per AE (van Vurren and Chillibroste 2013; Ash and Stafford Smith 1996).

The global emergence of enhanced data capture, data processing and communication is providing manufacturing and industrial processes with greater precision, control and automation. These data can be used to provide more efficient management systems (Hollen *et al.* 2013). We refer to the use of digital data within a management framework as an 'e-Management System'.

Generally livestock grazing systems have not used digital data as part of a formal e-Management framework. There are, however, examples where digital data have been an integral part of management, leading to opportunities to increase production outcomes (Wark *et al.* 2007). For over twenty years the global dairy industry has utilised radio frequency identification (RFID) technology to collect records of individual cow milk production (Eradus and Jansen 1999). The digital identifier from RFID technology has also been used to optimise in-parlour feeding based on both the stage of lactation and milk yield of individual cows (Eradus and Jansen 1999). More recently RFID technology has been used in the Australian National Livestock Identification System (NLIS) to track livestock movement between properties, auction markets and abattoirs. The Australian NLIS was initiated to support a bio-security regulatory framework, however, graziers are increasingly utilising the NLIS to aid management (Bailey and Britt 2001).

This paper considers the basis for an e-Management framework and explores the potential for e-Management to improve grazing herbivore production efficiency. Production efficiency is important but ultimately farmers need to make money, and economic efficiency incorporates the broader aspects of e-Management (*e.g.* labour efficiency or enhanced market access). The framework for e-Management relies on the acquisition of digital data (the 'e' part) and the use of the digital data to exert control over the system (the 'Management' part). The system control can be both manual and automated. Whilst this paper limits its content to domesticated herbivore grazing production it does, consider both intensive- and extensive-grazing systems. Although herbivore-grazing systems can generally be differentiated on the basis of the density of animals per unit area within the context of e-Management, the access to hard-wired digital infrastructure provides a secondary level of differentiation. Digital data can either be captured off-animal, enabling links to hard wired infrastructure, or on-animal, which relies on a wireless network.

What is an e-Management system and how does it relate to production efficiency?

An e-Management system uses digital data to aid management decisions. Good management involves collating information, which is used to inform a decision, resulting in a management action (Hollen *et al*. 2013). One type of information that can inform decision-making is digital data collected from both inside and outside the farm system. For herbivore grazing systems, the boundary of the system is the spatial-extent of the farm. Examples of digital data from inside the farm include livestock condition and or climate data collected by local weather stations. Digital information derived from outside the farm could include market prices delivered through the Internet, or satellite-derived data used to estimate forage availability.

Through the e-Management process, information that is used to inform a decision can be used to help predict future outcomes (Hollen *et al*. 2013). Selection of alternative management actions will be based on likely future scenarios (Wark *et al*. 2007). For example, measures of herbage biomass and rainfall can be used to determine when herbivores need to be moved from a paddock (Bailey *et al*. 1996). Strategic management uses information to inform long-term decisions. Reactionary management relies on updates of the state of the system to help make the best short-term decision (Hollen *et al*. 2013). In practice, grazing systems combine both reactionary and strategic management (Mungier *et al*. 2012). E-Management systems provide an opportunity to formalise the decision process and consider what information is relevant, and more importantly how the information can assist in deciding on a management action.

Predictive capabilities are dependent on inference and will have elements of approximation. Farm managers rely on previous experience to help predict future scenarios and inform their management decisions (Mungier *et al*. 2012). If the system is stable then previous experience can be a reliable method to inform a decision. For unstable systems, however, previous experience does not provide a reliable indicator for future outcomes. Managing grazing systems that are experiencing change, either initiated from within (*e.g.* due to the introduction of new farming methods), or from outside the system (*e.g.* from changes to markets requirements) requires new learning (Mungier *et al.* 2012). An e-Management framework provides the opportunity to consider the direction and change within the farm system and prepare management scenarios.

The productive capacity or production efficiency of a grassland-based system can be described as the ratio of inputs to outputs. Efficiency values can be used to describe varying parts and phases of the production cycle (Leach *et al*. 2002). For example, the breeding efficiency of beef production systems can be described as the number of calves born per cow or number of calves weaned per cow. Most efficiency metrics describe the ratio of annual outputs to inputs. While there are benefits in describing the biophysical efficiency of a small part of the enterprise this information only provides knowledge of a sub-set of the farm system (Leach *et al*. 2002). In practice e-Management systems need to relate to economic outcomes and economic efficiency.

For grassland based farming systems, the e-Management framework provides an opportunity to collect enhanced data to better understand the farm system and in so doing enable better management decisions. The e-Management system collects, collates and integrates information and can use inference methods to help make better decisions (Mugnier *et al.* 2012). Whilst e-Management certainly encompasses decision support systems (DSS) it extends beyond supporting a decision and can integrate automation for example automated virtual fencing (Ruiz-Mirazo *et al.* 2011). This automation includes data acquisition, data processing, and even management actions (Teng *et al*. 2012). Although farm-based DSS tools have always had a strong computer component, e-Management systems provide the opportunity to deliver an automated operating environment. This automation has become more effective with the availability of wireless sensor networks and the rise in smart phones that begin to provide computer capabilities in the paddock via tailored software (*i.e.* “apps”).

This paper explores what developments are needed to deliver a grazing livestock based e-Management system. Currently there is no single integrated e-Management system, rather a collection of sources of information that are used to help with decisions and that finally map into management actions. The evolutionary development of on-farm digital frameworks follows a path of increasing sophistication, with less reliance on hard wiring *i.e.* greater use of wireless networks, and increasing automation (Wark *et al*. 2007). We describe the technological developments and opportunities focusing on off-farm and on-farm digital data. The off-farm digital data covers a number of different data sources but focuses largely on pasture assessment using remote sensing. The on-farm digital data section emphasizes a range of data and technologies that are focused on measuring and managing the animal.

Off-farm digital data and the opportunities for e-Management

Off-farm digital data used for e-management decision making may have different spatial and temporal scales: remote observations of the farm area, such as from maps and remote sensing, regional observations of the area around the farm, such as weather predictions and regional-average production data, and distant observations that impact on the production system, such as export prices for livestock. We define remote observation of the farm as monitoring from a sensor that can collect data from a location that is not located on the farm property. There are a wide variety of sensors and platforms for remote monitoring, so we discuss some common combinations and use Australian examples that demonstrate how remote off-farm data can aid e-Management within a livestock context.

Remote observations of the farm area

Sensors that can monitor the farm remotely include:

- analogue or digital cameras that capture true colour (red, green, blue) images, with the potential inclusion of individual bands in additional wavelengths such as a near infrared (NIR) band sensitive to photo-synthetically active vegetation;
- multispectral or hyper-spectral sensors that record across multiple spectral bands from the visible wavelengths through the NIR, the short-wave infrared (SWIR) which is sensitive to the non-photo-synthetically active vegetation and soil, and into the thermal infrared which can be used to monitor frost-risk and map on-farm surface properties;
- sensors that monitor soil moisture and other bio-physical properties,
- sensors such as radar that can see through clouds and measure biomass; and
- sensors such as LiDAR that measure the morphology of the surface.

These sensors can be mounted on a range of platforms, including airborne platforms such as fixed-wing aircraft, helicopters, unmanned aerial vehicles (UAVs), or balloons. Satellite-based platforms can obtain imagery at daily to monthly (or less frequent) intervals. Optical satellite-based sensors are affected by moisture in the atmosphere. Robotic systems, which move across the farm, can also be used as a sensor platform and could be considered either an on-farm or off-farm platform.

Farm imaging, using an analogue or digital cameras (*e.g.* aerial photographs), represent some of the earliest remote monitoring technologies used for the earth, and have been widely available for farm mapping and planning. The spatial resolution of aerial photography is dependent on the height that the sensor is flown; however aerial photographs typically have high spatial resolution (*e.g.* cm scale pixel sizes). The level of processing determines the usefulness of the images, whether fully geo-referenced and able to be overlaid with other data, or less "stable" images such as those obtained from a UAV, although post-processing can improve image quality. The interval between aerial images is often long (years or decades apart), although custom over-flights can improve the frequency of repeat images. Very-high resolution satellite based images are more readily available (*e.g.* Worldview, Quickbird, Ikonos), and replicate the characteristics of pan-chromatic or 3-band aerial photography. Repeat monitoring using aerial- or satellite-based platforms provides data that can be used to monitor changes in feed-availability for tactical decision making, such as timing of cattle movements among pastures in rotational grazing systems.

Multispectral and hyper-spectral sensors are commonly used to monitor vegetation characteristics, which can aid feed budgeting, or mapping spatial utilization/over-use of pastures. Temporal changes to pasture characteristics can be determined using vegetation indices that utilise the NIR band, such as the widely used Normalized Difference Vegetation Index (NDVI, *e.g.* Tucker, 1979). There are many broad-band vegetation metrics that can be calculated from remote sensing data (*e.g.* Elvidge and Chen 1995). Calibration of vegetation indices to pasture biomass (*e.g.* Handcock *et. al.* 2009; Todd *et al*., 1998) or pasture growth rate (*e.g.* Hill *et al*. 2004) is more difficult as it requires calibration of raw images using on-ground and on-site measures. Other measures, such as fractional ground cover, are becoming more readily available over large areas, but they are recorded at relatively coarse scales (*e.g.* Guerschman *et al.* 2009). These coarse scale measures can be used to monitor the impact of grazing on ground-cover characteristics.

When using remote sensing for e-Management there is a trade-off between temporal frequency, spatial scale and cost. Frequent high-resolution images often provide optimal data but are expensive, while lower resolution images that are available less frequently are cheaper for mapping large areas, but may be less useful for smaller farms. Maps of remotely sensed vegetation indices (*e.g.* NDVI) capture spatial differences in vegetation "greenness" but unless they have been calibrated they are not directly related to measures of feed availability. Maps of vegetation indices and fractional cover that are used to monitor spatial utilization of pastures need expert interpretation. The technical requirements that are required to access and interpret remotely sensed data mean that grassland farmers often have to rely on consultants or other data providers to inform decisions in the context of an e-Management framework. Data access and interpretation is, however, becoming easier as e-Management tools become more accessible. For example, combining aerial photographs with other farm data such as fence lines within Geographical Information Systems (GIS) software allows strategic on-farm decision-making. The recent availability of aerial photographs and true-colour satellite images in free online mapping software such as Google Earth™ has enabled increased use of these data by non-experts.

More sophisticated analysis of remote monitoring data can be customized for a specific farm and delivered through an e-Management framework. An example of e-Management through off-farm remote monitoring is the Pastures From Space® system. Actual pasture growth rate, determined from coarse-scale satellite images and weather data is mapped for individual paddocks and is available weekly. These data enable both tactical and strategic management of feed resources (Hill *et al*. 2004). Customized reports for a property and surrounding areas are also available through the "FORAGE" web-based system (Grazing Land Systems, 2012), which provides modelled pasture characteristics and climate data and satellite-image maps in a report format. A more recent application, which is available on smart phones and other electronic devices, is the "SoilMapp" tool for accessing farm-specific soil maps from a range of Australian soil databases (*www.csiro.au/soilmapp*). Weather observations and short-term predictions are also available through on-farm weather stations, or from nationally interpolated grids (*e.g.* via the Australian Bureau of Meteorology).

Regional data from the area surrounding the farm

Many of the datasets that are used to monitor on-farm can also be used to monitor the area around the farm, particularly those from satellite data, which typically cover broad areas. As with on-farm monitoring, these datasets usually require software to process and interpret the data to provide information of larger areas. Also, many characteristics of these datasets suitable for e-Management on-farm require different interpretation when applied to broader areas. For example, non-farm areas (*e.g.* roads, towns, or forests) must be identified and considered separately from agricultural areas. Pastures from Space® products are available aggregated at the statistical local area level for monitoring forage growth rate.

Regional weather data can be used for short-term planning. Longer-term decisions are aided by climate observations, such as the El Niño-Southern Oscillation (ENSO) effect associated with large-scale shifts in weather patterns (Allan 1988). Other off-farm data that can be used in decision making are stock-prices, information about domestic and export markets for livestock, commodity prices for inputs such as fuel and fertilizer and information about labour availability. Increasingly these data sources are available in near real-time through internet and smartphone applications. However, access to off-farm data requires reliable network connectivity to the farm.

On-farm digital data and the opportunities for e-Management

Monitoring has been part of grassland production systems since livestock were domesticated. Both subjective (*e.g.*, animal size and shape) and objective (*e.g.*, weight) metrics are used to make selection decisions. The evolutionary trajectory of on-farm digital data is focused on grazing livestock and can be divided into four key phases; off-animal monitoring, on-animal monitoring, off-animal monitoring with automated control and finally on-animal monitoring with automated control. The terms on and off-animal refers to the location that the data is collated. For example RFID on radio transmitter devices that are fitted to an animal are simply sending data to an off-animal device for storage and processing.

Off-animal monitoring

The critical infrastructure that enables e-Management of livestock production is electronic identification (ID) (Bailey and Britt 2001). Most livestock electronic ID systems use a RFID device (Eradus and Jansen 1999). The electronic tag can either be fitted to the ear, around the neck or inserted as a rumen bolus. The unique RFID number is read when a reader interrogates the device. The reader can be a hand-held wand reader or a static panel placed in a suitable location where the animals are monitored. The electronic ID doesn't need to have a battery as the reader provides the necessary power to enable the device to send the ID back to the reader. If animals are forced to go past a reader in order then it is possible to automate data collection by linking bio-physical data with the ID *e.g.* live-weights or milk yields (Teng *et al*. 2012).

The requirement for the livestock ID to be read by a powered reader means that the integration of RFID technology in grazing systems necessitates the livestock go through a handling system to have their ID read (Eradus and Jansen 1999). These RFID systems have been widely used in the dairy industry as the cows go through a milking parlour (Stankovski *et al*. 2012). The RFID reader can be placed at the entrance to the parlour and the order that the cows enter linked to a milking machine. Individual records of milk production can be automatically collected (Stankovski *et al*. 2012). Similarly for meat producing livestock, it is possible to have a reader in an alley; this reader provides an ID and then allows the manager to record additional information such as animal live weight or pregnancy status linked to animal ID. There are examples where grassland farmers place systems at watering points or supplement feeders. As livestock travel to water they must pass through an alley and a weighing system records their weights and links it to their unique ID (Charmley *et al*. 2006).

The increased ease and automation in data collection that a RFID system provides facilitates the collection of additional production data, and researchers have used the technology to monitor grazing behaviour (Swain *et al*. 2003). These data can be linked to software systems that organise the information for use in management systems such as creation of genetic selection indices (Teng *et al*. 2012; Hirata *et al*. 2013).

Radio frequency identification has been the main low-power method for linking animal IDs with production data to monitor animal performance. There have recently been developments in radio tracking technology that could be utilised for livestock monitoring (*e.g.* Taggle http://www.taggle.com.au). These systems use low-powered radios that send an animal ID plus small packets of additional sensor data. The data is sent via radio receivers at predefined time intervals. With multiple receivers it is also possible to triangulate signals and determine the location of animals. These active radio-based tracking systems do all of the monitoring and data processing at the receiver station. The tag that sends the signal is located on the animal and doesn't receive data. The tag is internally powered and, depending on the frequency of transmissions, can last up to 3 years. The transmission-only tag has the capability to send low bandwidth data and can be used to provide a continuous flow of data on the location and performance of an individual animal. These tracking systems can monitor thousands of individual animals over a 25 km^2 area under ideal conditions.

On-animal monitoring

Monitoring activity of grazing animals using sensor technology that is located on the animal is a more recent development. The emerging technologies include activity sensors that use behavioural information to infer physiological states (Wilson *et al*. 2006). There are a number of practical considerations and associated challenges that an on-animal sensor needs to address. The first is fitting a sensor to the animal so that it remains in place and doesn't cause any physical damage to the animal by rubbing the skin or by getting caught in trees or animal handling facilities. The second is to be able to provide sufficient power to the device to enable it to operate within the constraints of the livestock production system. The final challenge is to be able to access the data so that it can be used as part of an e-Management system.

Devices have been fitted to the necks, legs and ears of grazing livestock (Wark *et al*. 2007, Swain and Bishop-Hurley 2007). For grazing livestock that are handled on a regular basis (*e.g.* dairy cows) it is possible to check and refit devices on when the animals go through the yards or parlour (Swain *et al*. 2003). The opportunity to check devices regularly means they can be located in positions that enable optimum data collection with less concern about the device being dislodged or displaced. In more extensive grazing systems the device needs to remain in place for prolonged periods of time and may be subject to physical damage as the animal rubs or knocks the device, or from inclement weather. The preferred option has been to fit devices using an ear tag, however, livestock researchers have had success in fitting devices to collars around the animal's necks. Ear tag devices are restricted in their size and this creates technical challenges for powering, sensing, data processing, data storage and data transfer.

Providing sufficient power for on animal e-Management systems is a significant challenge. There is a continual trade-off between functional ability and practicality. The ability to measure more information in greater detail requires increased power, but this results in larger and less practical devices. Current research development for on-animal monitoring technology of grazing livestock has been trying to develop lower power sensors that can deliver useful information. Examples include the use of on-animal transmitter technology to determine location information using a series of base station receivers. These devices aim to replace the more power demanding GNSS based receiver technologies (Swain *et al*. 2011).

Data storage and downloading creates problems particularly where an e-Management application involves monitoring animals in extensive inaccessible locations. The general approach has been to utilize some on-board data storage and then to use a wireless network to download the data when the animals congregate at a suitable location like a milking parlour or watering point.

There are a number of on animal sensor technologies. GNSS GPS have provided researchers with detailed information on the location and movement of grazing livestock (Swain *et al*. 2011). Unfortunately the financial cost and high power demands of this technology have prevented it being used within a more commercial e-Management system. Accelerometers are low powered devices that are proving to provide useful information on animal movement. The data has been used to infer behaviour and are providing useful practical information for identifying the physiological state of animals, for example cows that are on heat (Müller and Schrader 2003; Wilson *et al*. 2006; MacKay *et al*. 2012; Valenza *et al*. 2012). There are a number of other sensors that are being used by researchers that may have potential value but there is still more work to be done on the value proposition, examples of these technologies include proximity loggers, acoustic recorders, video images and bite meters (Patison *et al*. 2010; Rutter *et al*. 1997; McCowan and Dilorenzo 2002; Ungar *et al*. 2006; Laca and Wallis de Vries 2000; Griffiths *et al*. 2006). Proximity loggers have been used to identify social interactions and can provide information on mothering up and both maternal and paternal parentage (Swain and Bishop-Hurley 2007).

Off-animal monitoring with automated control

Further refinements to monitoring capabilities have included the development of automated control. The control systems are based around an RFID reader that link the ID of the animal to either data that is collected at the time control is implemented or secondary data that has been collected and analysed earlier. The combined data enables an automated e-Management task to be carried out. In intensive dairy production systems when cows enter the parlour, the in-parlour feeding system is pre-programmed and automated to feed the cow based on linking her ID to stage of lactation and milk yield (Stankovski *et al*. 2012).

Monitoring the performance of beef cows at pasture can be achieved with limited labour input by utilising a walk-over-weighing system (WoW) (Alawneh *et al.* 2011). In more extensive production systems, animals can be separated into different groups as they go to a water point based on either predefined management data or data that was collected from a WoW. For example, an auto-drafting system can be used to segregate animals at a predefined weight ready for market or to separate cows from calves. Other uses of the technology include identifying cow-calf pairs based on the frequency with which two animals pass through the WoW sequentially. This requires both the cow and the calf to be tagged, but can then provide information on the weight of the calf, which can be automatically separated from the cow at a predetermined weight. The identity of cow-calf pairs is often not available on extensive systems because the cattle are not observed regularly.

Similarly the WoW can be used to identify and separate poor-performing animals based on their live weight change (Brown *et al.* 2012). Poor performance could be the result of illness and require treatment. Likewise, poor performance could be the result of inferior genetic potential and such animals could be culled when nutrition becomes a limiting factor.

Herd-based information on weight changes could be utilised to indicate a reduction in biomass within the paddock and indicate the need to move animals to a different paddock (Brown *et al*. 2012). Using such systems for “self-mustering” reduces costs and stress on livestock.

On-animal monitoring with automated control

Autonomous animal control (AAC) or virtual fencing is a transformational technology that has the potential to significantly reduce costs and improve the production and sustainability of free-ranging grazing livestock (Ruiz-Mirazo *et al.* 2011). Being able to match forage supply with animal demand at any temporal or spatial scale would not only maximise utilisation but also minimise localised overgrazing (Ash *et al*. 1995). Animal production could also be maximised, assuming forage resources are well defined. In terms of cost reduction, AAC will allow grain producers to graze animals under controlled conditions without having to erect temporary fences or break up paddocks with permanent fences. There could also be cost savings by not having to erect and maintain traditional physical fences in environments where stocking rates are low or fences are regularly destroyed by natural events such as flooding.

However, for AAC to be successful would require a radical change in how grazing management is implemented within the grazing industries (Anderson 2001). Currently fences are perceived as a barrier that cannot be crossed. Research to date suggests that virtual fences may not be appropriate for boundary fences since the barrier is permeable, animals may cross the boundary, but they are discouraged from doing so. Based on animal behaviour, algorithms within the system define how the system responds. If for example an animal runs through the boundary the system shuts down until the animal has stopped running. Autonomous animal control devices use similar technology to that used for on-animal monitoring devices with some additional electronics to control the movement of the animal. The system works on the same principles of the electric fence except there is no fence. Animals are contained within virtual boundaries. Electric collars worn by the animals emit a sound to warn them that they are approaching a virtual boundary line. A mild electric shock is delivered should the animal ignore the audio warnings (Bishop-Hurley *et al.* 2007). With conventional electric fencing, animals have a visual cue of the fence's physical presence; with the virtual fence, as algorithm on computers are used to define the boundary, auditory and tactile cues are used instead. The animals learn to associate the audio cue with the tactile stimuli control. In trials over two to three weeks, the combination of stimuli has been demonstrated effective with the cattle taking less than an hour, (an average of seven approaches) before they learnt to move away from the boundary based on the cues alone.

Conclusions

Over the last twenty years there have been significant developments in technologies that can measure and transmit digital data. The increasing array of digital data sources from both external and internal to grazing based systems creates opportunities for e-Management systems. The challenge is to integrate data and link it with a decision and management outcome that has direct value. Integrated and even automated e-Management systems have not yet realised their full potential. This will only occur when the economic value of individual and combined datasets are identified. There are still challenges to overcome with the development of sensors that are sufficiently robust and practical for grazing farmers. Researchers that investigate grazing systems have developed and used systems that might have commercial value for graziers, and there is growing evidence that the research findings may point towards future commercial applications.

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